Estimating Rates of Nutrient Depletion in Soils of Agricultural Lands of Africa

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The work presented in this report is an outcome of IFDC's multidiscipinary programs and activities that are being conducted to promote a more productive and sustainable agriculture in Africa and other regions of the world. The report is a contribution of IFDC work to the goals of inter-institutional efforts and initiatives such as the Soil Water Nutrient Management Initiative of the CGIAR, the Desertification Convention, and the Initiative for Soil Fertility Improvement.

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List of Acronyms and Abbreviations

USAID .... United States Agency for International Development
GDP .... gross domestic product
FAO .... Food and Agriculture Organization
IFDC .... International Fertilizer Development Center
AGZ .... agroecological zones
USDA .... United States Department of Agriculture
UNEP .... United Nations Environment Programme
GIS .... geographic information systems
ESRI .... Environmental Systems Research Institute
USLE .... Universal Soil Loss Equation
LGP .... length of growing period
NPK .... means addition of the major nutrients nitrogen, phosphorus, and potassium in the form of N, P_2O_5, and K_2O

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Summary

Because the agricultural sector is often the most important sector of the economies of developing countries, its performance substantially influences the economic growth and quality of life of the people in those countries. This is particularly apparent in many countries of Africa where agriculture accounts for more than 25% of the gross domestic product (GDP) and is the main source of income and employment to the rapidly expanding population in most countries. A high percentage (65%) of the people in Africa depend on agriculture for their livelihood. Therefore, it is not surprising that increasing agricultural production can make a major contribution to economic growth, social improvement, and trade on the continent.

Africa's population continues to grow at higher rates than on any other continent. In recent decades, the continent's population has been increasing at an annual rate of about 3% or by more than 14 million people every year. Estimates indicate that by the year 2020, Africa will need to import more than 30 million metric tons of cereal each year to fill the gap between the demand and supply. Population pressure on land resources is forcing farmers to cultivate more areas of marginal lands, further degrading the rather limited resource base for agriculture. Also, migration from rural areas to urban centers has been increasing, causing more poverty and social instability in the cities. Much of Africa's agricultural land is being degraded because the intensification of land use for agricultural production, which is necessary to satisfy increased food demands, is occurring without the adoption of proper management practices and external inputs.

Overcoming chronic problems that lead to degradation of agricultural land in Africa requires a good understanding of the interplay among biophysical, agroclimatic, economic, and human factors that determine the management of natural resources and prevailing farming systems. In this study, current rates of nutrient depletion in soils of agricultural areas of Africa are estimated to identify and characterize regions where the nutrient mining of soils is becoming a factor in land degradation and a major constraint to the sustainable intensification of agricultural production. Estimates of the amounts of nutrients required to balance inflows and outflows of nutrients and thus prevent nutrient depletion are provided as useful indicators for the design of soil and fertilizer management strategies that can be adopted to prevent land degradation and increase production. The development of nutrient depletion indicators relies on the use of cross-sectional (spatial) and time series data. Methods, procedures, and computer programs to estimate nutrient flows and balances were developed, tested, and adapted from previous studies. Estimates of nutrient depletion are analyzed in the context of prevalent circumstances such as current levels of crop production, inherent soil fertility conditions and resilience (or fragility) of the soils, biophysical and agroecological environment, and population density.

The estimation procedure uses data on agricultural production and agricultural areas from various secondary sources (various United Nations agencies, including the Food and Agriculture Organization [FAO], and The World Bank). The baseline data is integrated into a database and monitoring information system to produce attribute and geographical information on agricultural land resources, crop production, nutrient balances, and nutrient requirements. This information should be updated periodically to reflect changes over time in the management of agricultural lands, crop production technology, and the use of external inputs across areas, countries, and regions.

An analysis of crop production and nutrient depletion estimates for the period 1993 to 1995 indicated that agricultural production in Africa has been stagnant or declining in many countries and soils are often losing high amounts of nutrients. In the semiarid, arid, and the Sudano-Sahelian areas that are more densely populated, soils are losing 60-100 kg NPK/ha annually.[1] The soils of these areas are shallow, highly weathered, and subject to more intensive cultivation with low use of mineral fertilizers (0-6 kg NPK/ha/year). Water availability and intensification of land use due to population pressure have restricted crop diversification and the use of proper management practices. In addition, the length of the growing season is very short, less than 140 days, increasing pressure on land. In most areas, the demand of the current population exceeds the potential productive capacity of the land. Other important agricultural areas such as those located in the subhumid and humid regions and in the savannas and forest areas show high variability of nutrient losses. Rates of nutrient depletion range from moderate depletion such as in the humid forests and wetlands areas in southern Central Africa and Zaire to more than 100 kg NPK/ha/year in the East African highlands. The soils in these areas are characteristic of the weathered Ultisols and Oxisols of the tropics.

Estimates of average rates of nutrient depletion by country show the highest rates of nutrient depletion (>100 kg NPK/ha/year) in Rwanda, Burundi, and Malawi where fertilizer use is very low and high losses of nutrients occur mainly as a result of soil erosion. Soils of most countries in North Africa are being depleted of nutrients at rates ranging from 20 to 50 kg NPK/ha/year. Agriculture in the coastal areas of Libya, Egypt, Algeria, and Tunisia is characterized by the high application of mineral fertilizers with moderate rates of nutrient depletion. A contrasting agriculture is practiced in the forest humid areas in sub-Saharan Africa where increased population density and low-intensity agriculture cause high rates of nutrient depletion.

A number of useful observations can be drawn from nutrient balance and depletion estimates. A very clear observation is that the continued lack of application of required nutrients is causing soil nutrient depletion and reduction of agricultural productivity in most agricultural areas in Africa. Major factors contributing to the depletion of nutrients are soil erosion for phosphorus and soil erosion and leaching for nitrogen and potassium.

1. NPK is used in this paper to indicate the addition of the major nutrients nitrogen, phosphorus, and potassium in the form of N, P_2O_5, and K_2O.

Nutrient gains in soils of Africa are low and occur through mineral fertilization, nutrient deposition, and nitrogen fixation. These low gains contribute to the high rates of nutrient depletion that are often present. The inherent low mineral stocks of Africa's soils and the climatic conditions characteristic of the vast interior plains and plateaus aggravate the consequences of nutrient depletion. High population growth rates have caused increased pressure on land and intensification of agriculture without proper management and addition of nutrients. This situation is decreasing the nutrient reserves of soils in most of the semiarid and subhumid areas of sub-Saharan Africa.

For this study, quantities of nutrients required to prevent nutrient depletion and sustain crop yields were estimated for various crops and for cropped areas in each country. In many instances, even drastic measures, such as doubling the application of fertilizer or manure or halving erosion losses, would not be enough to offset the calculated nutrient deficits (negative balances). The current average use of nutrients for Africa is about 10 kg NPK/ha/year. The estimated average use required to meet nutrient needs at current levels of production (1993-95) is about 40 kg NPK/ha/year. In addition to the application of mineral fertilizers, long-term management practices such as the use of soil conservation measures, recycling of crop residues, livestock management, and use of organic fertilizers will be required.

An analysis conducted using the nutrient balance models in two countries in the semiarid and subhumid areas showed that recycling crop residues, increasing nutrient fixation through crop rotations, and applying organic fertilizers could reduce significantly the rates of nutrient depletion. Such practices could also reduce the mineral fertilizer requirement by as much as 44% of the amount of nutrient that should be applied to maintain current average levels of crop yields.

In view of the continued degradation of land in Africa, national governments with the support of the international community must take the lead in confronting the problems of nutrient depletion, land degradation, and decline in the productivity of agriculture. Significant policy changes will be required to establish an environment conducive to the efficient use and availability of agricultural inputs and the improvement of local extension services and farmer support. Structural adjustments, market development, trade and pricing policies, infrastructure improvement, and institutional support services should be reevaluated and assessed in terms of their impact on the resource base and the sustainable expansion of agricultural production and productivity.

This report is part of the International Fertilizer Development Center's (IFDC) efforts to develop information management systems that provide information on key indicators of soil fertility status and changes affecting crop production and the conservation of land resources. Periodical assessment of agricultural areas should be conducted to identify regions and sites where nutrient depletion or the excessive use or accumulation of nutrients severely limits crop production, degrades agricultural land, and causes serious environmental disturbances. The dissemination of information identifying areas/countries/regions where policy interventions are needed to prevent the tremendous damage that the continuous depletion of nutrients can cause to the environment and the resource base for agriculture is crucial to make correct and well-informed decisions.

The information, methodology, databases, and procedures described in this report should be viewed as a process subject to continuous improvement and refinement in terms of methodology, data, and outcomes. IFDC is involved in the task of enhancing methodological approaches and the quality of data and information that are crucial for improving agricultural production and conserving the natural resource base and the environment in developing countries. The periodical evaluation of nutrient requirements, balances, and rates of nutrient depletion in agricultural areas of developing countries is a key component of this effort. Analysis of this information in conjunction with the use of other pressure indicators will facilitate the identification of "hot spots" or areas where the resource base is being degraded.

It is important to note that the approach, methods, and procedures presented in this paper can be used as tools to generate information on the relative contribution of various agroclimatic and socioeconomic factors to nutrient imbalances and depletion in soils of agricultural lands. Such information is useful in conducting economic analyses to identify, for instance, policy interventions (and investments) that will have a greater impact on the prevention of nutrient depletion and land degradation and on the economic returns to farmers. These types of analyses are, however, beyond the scope of this document. The approach can also be used to simulate outcomes of various scenarios of levels of population density, crop production, agricultural intensification, and soil and crop management practices on soil nutrient balances. As tools for analysis and evaluation, these methods and procedures can also be applied to smaller scales such as regions, states, or districts within a country or to larger scales such as by continent or globally.

The estimates presented and discussed in this report should be viewed as the "best first approximation estimates" that can be calculated at this time. Although they can be improved, these estimates provide a good approximation of the order of magnitude of nutrient depletion. With the support of international donors, IFDC will continue its efforts to improve the quality of nutrient balance estimates and will periodically update and publish this information.

Estimating Rates of Nutrient Depletion in Soils of Agricultural Lands of Africa

Introduction

Africa's population continues to grow at higher rates than on any other continent. At an annual increase of about 3% in recent decades, the continent's population has been increasing by more than 14 million people every year. Estimates indicate that by the year 2020, Africa will need to import more than 30 million mt of cereal each year to fill the gap between the demand and supply. Population pressure on land resources is forcing farmers to use land more intensively and to cultivate less fertile soils on marginal land areas. In addition, agricultural production in Africa is hampered to a large extent by the predominance of fragile ecosystems, low natural soil fertility, and the low use of external inputs, principally mineral fertilizers. The more widespread deficiency of plant nutrients in soils of most agricultural lands in Africa is having adverse consequences for crop production and soil fertility maintenance. The continuous assessment and monitoring of plant nutrients in soils of agricultural lands and an improved understanding of the main sources (causes) of soil nutrient depletion are essential to identify appropriate measures for reversing trends in nutrient depletion and the decline in soil fertility. A significant increase of agricultural production depends on the adoption of modern technology, especially much greater use of mineral fertilizers and improved crop management techniques that can increase yields while protecting the integrity of the resource base.

This report presents methods and procedures for using time series and cross-sectional spatial data and information on agricultural production and inputs use to assess the effect of agriculture on nutrient mining and land degradation. Estimates of nutrient depletion are calculated at regional and country levels. Also, nutrient requirements for crop production are calculated by country and agricultural region. The report also outlines some of the consequences of nutrient depletion and the actions that may be taken to mitigate nutrient imbalances.

Estimates of nutrient depletion and requirements are derived by taking into account 1993-95 crop production technology and management practices, nutrient uptake by crops, nutrient recycling and soil nutrient losses through leaching, erosion, fixation, and other pathways. Nutrient inputs from organic and mineral fertilizers, nutrient deposition, and nutrient inflows from other sources including biological nitrogen fixation are also estimated.

Population density with respect to agricultural areas, climate patterns in agroecological zones (AGZ), and soil fertility assessments based on soil classification schemes developed by the United States Department of Agriculture (USDA) and FAO are used as additional indicators to associate nutrient balances with the degradation of agricultural lands. The sensitivity of the nutrient balance model to crop management was tested by using data from Zimbabwe, which is located in Southern Africa, and Mali, located in the Sahelian zone in West Africa.

An Overview of the Characteristics of Agricultural Land in Africa

African countries show diversity in endowment of agricultural resources. The total area of land in Africa that could be considered as potentially suitable for agricultural production is estimated at 874 million ha, about 27% of the continent's landmass. It has been estimated that in 1993 in Africa, about 196 million ha was cultivated, including 88 million ha under fallow, and, of this area, accounting for fallow, only about 108 million ha was harvested that year (FAO, 1993). One-third of Africa's land area is too dry to support rainfed agriculture. Most of the unused agricultural land in Africa lies in the humid Central region. This is a region where infrastructure is particularly poor, where the incidence of human, livestock, and plant disease is high, and where exceptionally variable rainfall can severely limit agricultural production.

Socioeconomic, policy, and biophysical constraints, in general, and soil-related constraints and management practices, in particular, are factors identified as major causes of low crop production, soil fertility decline, and, ultimately, degradation of the agricultural land in most countries of Africa. Inadequate replenishment of removed nutrients and continued loss of organic matter from the soils are contributing to increasing erosion rates and the decline in the fertility of the soils. It is estimated that between 1945 and 1990, nutrient depletion in Africa caused light degradation of 20.4 million ha, moderate degradation of 18.8 million ha, and severe degradation of 6.6 million ha (Oldeman et al., 1990).

Chemical and physical degradation affects most of the present agricultural land in Africa. The soils have poor nutrient retention capacity, and many are heavily leached and eroded. Superimposed on these inherently fragile resources and constraints is the continuous removal through cropping of plant nutrients in quantities that are significantly greater than those being returned to the soil by mineral or organic fertilizers. Average rates of nutrient depletion during the past 30 years from the cultivated land in 37 countries, excluding South Africa, indicated losses of about 660 kg/ha of nitrogen, 75 kg/ha of phosphorus, and 450 kg/ha of potassium per year (Stoorvogel and Smaling, 1990; Smaling, 1993).

Events of extensive degradation of agricultural land have been documented in locations of the more highly populated regions of dry land areas in West and East Africa. In the Peanut Basin of Senegal, continuous cultivation, along with low use of mineral and organic fertilizers and inadequate soil management practices, has exhausted the soils (Charreau, 1972; GDPA cited by Pieri, 1989). Farmers have been migrating eastward and southward to reclaim new lands. In the highly populated Mossi Plateau of Burkina Faso, millet areas have been degraded by continuous cropping (Broekhuyse, 1983). Many farmers have migrated temporarily to coastal countries. Because coastal opportunities are declining, however, Mossi farmers are increasingly adopting conservation practices (Sanders et al., 1994), and others are migrating to subhumid regions of coastal areas of Benin, Ghana, and Côte d'Ivoire. In northern Nigeria, around Kano, where population density is high, soil fertility has been depleted due to poor crop management practices (Smith, 1994). Soil fertility decline has been a major factor influencing food security in the area and the economy of the country.

Mali, Niger, and Togo are among the Sahelian countries where trends for maize, millet, and sorghum yields have been stagnant or decreasing due to continuous cropping, poor soil management, and low use of mineral and organic fertilizers (IFDC, 1992; FAO, AGROSTAT, 1994). In highly populated areas in central and southern Sudan, Ethiopia, and western Kenya, the continuous cropping without external inputs has decreased production and depleted severely the fertility of the land (Hoekstra and Corbett, 1995). Data from a long-term trial in western Kenya shows that, after 18 years of cultivation of continuous maize and common beans (*Phaseoulus vulgaris L.*) in rotation and without the use of nutrient inputs, the soil has lost about 1 mt/ha of soil organic nitrogen and 100 kg/ha of organic phosphorus. Maize yields decreased from 3 to 1 mt/ha during that period (Swift et al., 1994).

In addition to socioeconomic circumstances, land degradation in West and Central Africa has been associated with the management and maintenance of the agricultural resource base. The management of soils and agricultural systems is based on the low use of external inputs and continued exploitation leading to soil mining processes. On the most intensively used lands in the interior plains and plateaus, the soils have low stocks of nutrients and are difficult to manage due to the low content of organic matter and the presence of clay fractions dominated by kaolinite, halloysites, and/or iron aluminum oxides (Ssali cited by Rhodes et al., 1995). The soils have become strongly weathered and leached, and the cation exchange capacity of the soils is dominated by their low organic matter content. This implies that essential elements such as phosphorus, potassium, and calcium rapidly become scarce and acidity increases if proper management is not used. Nutrient balance studies performed by Pol (1992) and by Stoorvogel et al. (1993) showed that nutrient depletion is severe in densely populated areas in Mali, Nigeria, Ghana, Côte d'Ivoire, and Chad where agriculture is intensive and less than 30% of the land is considered fallow.

In the Sudano-Sahelian and Southern Africa regions, the intensive mixed farming systems are located primarily in pasture and savanna areas where soil nutrient content is low and where nutrient depletion and deficiencies are becoming major constraints. Breman (1994) evaluated nutrient depletion in pasture systems and the consequent impact in the sustainability of livestock systems in the Sahel. About 50% of the vast Sahelian grazing lands located on sandy soils with very low soil fertility are affected by high nutrient depletion rates. Low nutrient stocks in the soils and low water availability limit the agricultural potential of these lands. Agroforestry-based systems in the Sudano-Sahelian region of West Africa are also limited by the very low nutrient reserves of the soils. Breman and Kessler (1995) quantified nitrogen and phosphorus balances on these systems in West Africa. They concluded that competition for water and light constrained the use of agroforestry systems as a means to prevent nutrient losses (leaching and erosion) and land degradation.

In the tropical moist forest and savannas that are characteristic of the humid and perhumid areas and that predominate in Cameroon, Congo, Ghana, Nigeria, Gabon, Zaire, and part of Uganda, the intensification of agriculture and the clearing of forest areas due to population pressure are major sources of land degradation. Slash-and-burn practices combined with the continuous shortening of fallow and low recycling of crop residues are typical of the agriculture in these regions. Most soils are very fragile and low in plant nutrients. The nutrient recycling mechanisms that sustained the natural fertility of soils are being disrupted, land is being degraded, and soil fertility is dropping in such a way that it is often not possible to sustain even marginal levels of productivity (Lal et al., 1986; Kang et al., 1990).

Population pressure and poor crop management practices coupled with the topography make the mountain and hilly areas of Africa prone to excessive water runoff, soil erosion, and soil nutrient depletion. Specific areas identified by the United Nations Environment Program (UNEP, 1991a) as warranting special consideration include the Fouta Djallon mountains in West Africa (Guinea), the East African highlands (Kenya, Burundi, Ethiopia, Rwanda, Tanzania, Malawi, and Zimbabwe), and the highlands of Southern Africa (Botswana, Lesotho, and Swaziland). Stocking (1986) estimated the economic costs of the nutrient loss (N, P, and K) by soil erosion in Zimbabwe. The annual losses of N and P alone amount to about US $ 1.5 billion/year. Because of severe shortages of energy and fodder, the continuous cropping on steep slopes, and the low use of fertilizers and crop residues, the land has been severely degraded in some of these areas, principally in Rwanda, Burundi, Malawi, and Lesotho. Recycling of plant nutrients is highly desirable in these regions although competition for firewood and fodder to feed animals prevents a significant quantity of nutrients from being returned to the soil.

Irrigation and mineral fertilizers combined with improvements in crop varieties and management have been key factors determining increased agricultural production in most of North Africa and some Sudano-Sahelian countries. In Egypt, where rainfed potential is very limited, the irrigated area is about three times the area cultivated under rainfed conditions. In humid Central Africa, most of the land receives ample rainfall and irrigation is relatively undeveloped. In East and Southern Africa, irrigation is more frequently used in Madagascar, Swaziland, and Mauritius – accounting for about 32%, 22%, and 13%, respectively, of the area under permanent and temporary crops (UNEP, 1991b). In these irrigated land areas, land degradation is affected by economic, social, and technical factors. Such factors are basically related to the following characteristic features of irrigation: waterlogging and salinization, excessive lowering of water tables in some regions, build-up of pollutant concentrations in groundwater, and nutrient losses by leaching, lixiviation, and denitrification. All of these factors affect production systems and can degrade land in one or more ways (Stangel, 1991; Massoud, 1974).

Establishing a Geo-Reference Base for Rates of Nutrient Depletion and Requirements

Methodological Approach

The methodological approach used here to estimate nutrient balances and rates of nutrient depletion and requirements combines information on agricultural production, soil characteristics, and biophysical constraints with methods and procedures designed for making such estimates. The information and data related to agricultural production include land use, population-supporting capacity of land, crop production, and use of mineral and organic fertilizer. Attribute and geographic database systems are used in conjunction with empirical and mechanistic models to produce information for analyses and monitoring.

The approach builds upon pioneering work on nutrient balances conducted by Smaling, Stoorvogel, and others (Smaling and Fresco, 1993; Smaling, Stoorvogel, and Windmeijer, 1993). This building on previous work involves the linking of methods and procedures for estimating nutrient balances with attribute databases and geographic information systems (GIS) to integrate data and information in a common geo-reference base and to illustrate in the form of maps and graphs estimates of nutrient balances and rates of nutrient depletion from soils of agricultural lands at country and regional levels.

Attribute data used include crop areas and levels of production, as well as nutrient uptake for 10 crop groups that include 90 major food and industrial crops. The crops included in the database account for about 95% of the total cultivated area in Africa. Uptake rates for nitrogen, phosphorus, and potassium for each crop are estimated using data from field studies. Time series data on crop production and crop areas for the period 1961 to 1995 (FAO, 1994; FAO, yearbook series) and on mineral fertilizer consumption by country and region for the period 1985 to 1995 are included in the database. Information on organic fertilizer use and practices is also a component of the database. These data combined with information on crop and soil management systems, soil constraints, soil characteristics, and climate by region and country were assembled into a database management system.

The database management system was established using Access database management software (Gifford et al., 1997). This is a relational database system where data are assembled in tables of two-dimensional arrays called relations. The tables are related by indexes. A summary of the information included in these tables is presented in Box 1. The database contains modules for data management, statistics, and report production and is connected to routines for statistical analysis and estimation of model parameters (SAS Institute, 1993).

Box 1. Types of Data Included in Database Management System

Class	Table	Information
1	Agricultural	Crop area
		Crop production
		Fertilizer use
2	Soils	Soil classification (FAO)
		Soil classification (USDA)
		Soil fertility – class – constraints
3	Climate	Rainfall
		Agroecological zones
4	Management	Crop variety – management
		Production potential
		Nutrient uptake
		Crop residue – manure used
5	Economic	Crop prices
		Fertilizer prices
6	Socioeconomic	Population
7	Fertilizers	Fertilizer products – composition
		Fertilizer management
8	Experimental	Experiment results

The system is flexible and can be expanded to include additional data (tables) at the country and regional scales. The database is linked to a geographic information system (ARC/INFO and ARC/VIEW[1]) that is used for producing geo-referenced input data and map analysis and for presenting results in the form of maps or spatial outputs (Lane, 1996a and 1996b). The GIS contains information on soils, agroecological regions, climate, population, land use, soil fertility classes, and soil classification systems defined according to major taxa of the region (Buol, 1972; FAO, 1993; FAO, 1976; Landon, 1984). The GIS can be expanded to include coverages that identify area constraints and land quality indicators that can be used for improving soil and land management practices or for finding areas suitable for agricultural intensification. The whole system can be linked to decision support systems that include crop simulation models and optimization routines. A flowchart describing the approach used to integrate the various components of the system into a geo-referenced system to estimate nutrient depletion and requirements is presented in Figure 1.

1. Manufactured and distributed by Environmental Systems Research Institute (ESRI).

A GIS-based approach can have a number of limitations in dealing with complex resource use questions. The use of modeling is restricted, particularly in image-based systems. There is often no indication of the reliability of estimates based solely on GIS data. Modeling and decision support systems, however, can be used as tools to interpret and assist GIS in overcoming some of these problems. Modeling and decision support systems are particularly useful to deal with inconclusive statements and to explain the decisionmaking process adopted in arriving at various decisions. Interfacing decision systems with GIS can provide very powerful decisionmaking tools for formulating resource-management plans that promote a sustainable agriculture.

Basic Components of a Nutrient Balance Model

Pieri (1983), Gigou et al. (1985), Stoorvogel et al. (1993), Smaling et al. (1993), Duivenbooden (1990), and Pol (1992) among many other researchers have calculated soil nutrient depletion by using various approaches and

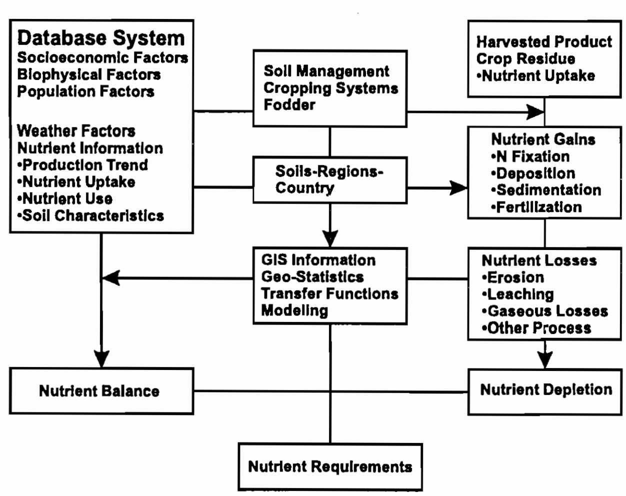

Figure 1. Geo-Referenced System to Estimate Nutrient Depletion and Requirements.

methods to estimate soil nutrient balances. A simple specification of the balance of nutrients (N, P, and K) in soils of agroecosystems at a country or regional scale is given by the following equation (Follet et al., 1987; Miller and Larson, 1992):

$$Rn_{tn} = \Sigma^{tn} (AP_t + AR_{\Delta t} - RM_{\Delta t} - L_{\Delta t}) \qquad (1)$$

where Rn_{tn} is the quantity of inorganic and organic nutrients remaining in the soil at time tn; AP_t is the soil inorganic and organic nutrients present at time t; $AR_{\Delta t}$ is the inorganic and organic nutrients added or returned to the soil during the time interval Δt. The $RM_{\Delta t}$ estimate is the plant nutrients removed with the harvested product and residue management during the time interval Δt, and $L_{\Delta t}$ is the inorganic and organic nutrients lost during the time interval Δt. The value of t represents the beginning time period, tn represents the ending time period, and Δt is the time interval between t and tn.

The equation states that if the amounts of nutrients removed from the soil (nutrient outflows) are greater than the additions (nutrient inflows) either by fertilization or management practices, then the reservoir or stock of nutrients within the soil pool will decline. Exact determination of different soil nutrient pools is very difficult because of the complex dynamic and stochastic nature of processes of nutrient transformations in the soil system.

The production of crop outputs and residues is used to calculate total crop nutrient uptake from soils. Nutrient depletion and requirements are assessed by calculating and using estimates of nutrient gains attributable to the application of mineral and organic fertilizers and to biophysical processes of deposition, sedimentation, and fixation. Information on weather and soil constraints, soil characteristics, and agroecological zones is used to estimate soil nutrient losses due to erosion, leaching, and volatilization (gaseous losses). Estimates of nutrient gains and losses are developed from assumed soil-nutrient transfer functions and from estimation of empirical statistical models (Larson and Pierce, 1991; Van Diepen et al., 1991; Bouma and Van Lanen, 1987; Smaling et al., 1993; Stoorvogel et al., 1993).

Assessment of Nutrient Outflows

Empirical nutrient loss models and transfer functions are estimated and used to calculate removal and assess nutrient losses through various mechanisms and processes. Further research and improvements in data should enhance the reliability of these models as predictors of nutrient transfers and losses through various processes. The specification and estimation of these models are described below.

Harvested Product (Nu) – The harvest of crop outputs and removal (export) of crop residues are major mechanisms of nutrient removal. Average values of N, P_2O_5, and K_2O uptake in kilograms per hectare were obtained from the literature and from experimental data. The nutrient uptake (Nu) in harvested product (j) and country (i) was calculated by multiplying total crop production in metric tons (Cp_{ij}) by the crop nutrient uptake index (NI_j) expressed in kilograms per metric ton:

$$Nu_{ij} = Cp_{ij} (NI_j) \qquad (2)$$

Values of crop nutrient uptake indexes (NI_j) were derived from the literature and from experimental results (Russell, 1973; Van Keulen, 1986; Sanchez, 1976; Stoorvogel and Smaling, 1990, Fried and Broeshart, 1967; PPI, 1988). These indexes were estimated for crop yields of traditional and improved crop varieties under average management conditions. Nutrient uptake values for main crops are presented in Appendix I (Table I.1).

Crop Residues (Nr) – Indexes of content of N, P_2O_5, and K_2O in crop residues were obtained from references and field studies (Lal, 1995b; Geiger et al., 1992; Larson et al., 1978; Bationo and Mokwunye, 1991; Bationo et al., 1994; Prasad and Power, 1991). The nutrient removed from the soil by crop residues was calculated by multiplying the nutrient content in the residue (NI) by the crop production data (Cp) for countries and regions, the harvest index (HI) and the approximated percent of residue left on the soil after crop harvesting (Ref). Thus, the amount of nutrient uptake in the residue removed from soil for a given crop (j) in country/region (i) is determined by the following equation:

$$Nr_{ij} = Cp_{ij}\,(1\text{-}HI_j)\,NI_j\,Ref_j \qquad (3)$$

where Nr_{ij} represents the nutrient uptake in crop residues, in metric tons or kilograms per hectare, depending on the crop production values. Estimated mean values of nutrient uptake in crop residues are presented in Table I.1. Estimates of the amount of residue left on the soil after harvesting and grazing were obtained from references and country reports. The harvest index (HI) measures the proportion of the economically produced part of the biomass that is actually harvested.

Leaching of Nutrients (Nl) – Leaching is an important mechanism of nitrogen and potassium loss for shallow-rooted crops in sandy soils of the semiarid zones and areas of Sudano-Sahelian Africa. Soil P leaching is considered to be negligible in the tropical soils of Africa. Leaching of N and K have been found to be highly associated with the amount and method of nutrient application (management), the soil physical characteristics, the climate, and the crop species and varieties being grown on the soil. Nitrogen and potassium losses can be very high and are associated mainly with the rainfall intensity, low soil moisture, and poor water retention capacity of soils in most semiarid areas. Leaching periodically removes most of the nitrate N from the profiles of permeable soils in cropping systems of the humid and subhumid areas of sub-Saharan Africa (Dudal and Byrnes, 1993).

Most of the literature on nutrient leaching is confined to information on point observations for N and K, which are variable and difficult to extrapolate (Charreau, 1972; Pieri, 1985). Other authors (Addiscott and Wagenet, 1985; Burns, 1975; Bouma and Van Lanen, 1987), using experimental data, have developed empirical transfer functions and used them for prediction. They have shown that N leaching can be predicted reliably in an African environment on the basis of information on rainfall, soil moisture content, and nutrient content of the soils. Regression models were estimated to predict nutrient leaching at country and regional levels. The general specification of this model includes as variables the fertility of the soils expressed as soil fertility class (Fc), the average rainfall (R) for the region/site, and the nutrients applied (Cn). The model was specified as follows:

$$Nl_i = \alpha + (\beta_1 + \beta_2 R)Fc + \beta_3 \log(R) + \beta_4\,Cn + \varepsilon_i \qquad (4)$$

where $100 < R < 3300$ and Nl_i is the amount of leaching of N or K at site i, expressed as percentage of the quantity applied; the parameter estimates α, β_1, β_2, β_3, and β_4 measure the effects of site management, soil fertility class (Fc), rainfall (R) in mm/year, and nutrient applied in the form of mineral and/or organic sources (Cn), respectively. The soil fertility class Fc is included to account for the fertility and management of the soil as determined by soil classification and availability of soil nutrients. This is broadly assessed as 1 for low; 2 for moderate; and 3 for high. The parameter ε_i is the error associated with the estimation of the model. An example of the parameter estimated at the country level is presented in Table 1.

Nitrogen Gaseous Losses (Ng) – N is lost to the atmosphere by denitrification and volatilization. Small losses by volatilization of ammonia may occur in some alkaline soils. The likelihood of such losses is increased in sandy soils with low cation-exchange capacities. The loss through denitrification is more serious in Africa and is influenced principally by climate (rainfall), soil type (soils with high clay content), low N substrate availability, and crop uptake (Smaling, 1993; Mengel, 1985).

Table 1. Parameter Estimates of Models of Nitrogen and Potassium Depletion Due to Soil Leaching

Variables	Parameters	Estimates Nitrogen	Estimates Potassium
Intercept	α	20.54^{+} (15.33)	22.86* (11.51)
Soil fertility class (Fc)	β_1	-7.87** (1.90)	-7.09** (1.60)
Fc x Rain (R)	β_2	0.003^{+} (0.002)	0.001 (0.001)
Rain (log [R])	β_3	2.00 (2.28)	1.09 (1.71)
Fertilizer use (Cn)	β_4	0.58** (0.17)	0.68** (0.19)
Statistics:			
Mean (%)		30.69	24.99
C. V. (%)		18.04	16.00
Standard error (%)		5.53	4.20
R^2 (adjusted)		0.59	0.53

**Statistically significant at 0.01 level of significance ($p \leq 0.01$).
*Statistically significant at 0.05 level of significance ($p \leq 0.05$).
$^{+}$Statistically significant at 0.10 level of significance ($p \leq 0.10$).

Standard errors are in parentheses.

Dependent variables:
Nitrogen = Amount of N leached as percent of nitrogen uptake.
Potassium = Amount of K_2O leached as percent of potassium uptake.

Experimental data were used by Smaling and Fresco (1993) to predict denitrified soil N in Kenyan soils. Losses of N through ammonia volatilization can also occur in tropical areas with high use of fertilizer and organic sources of N and are influenced mainly by soil texture, pH, and climatic factors (Hargrove, 1988). Nutrient losses through both mechanisms are included in calculating N balances. A model was specified to predict these losses of N. This model included as variables rainfall (R), soil fertility class (Fc) to account for soil factors, and the quantity of nutrients applied (Cn) as proxy of N availability. The estimating model used had the same form as model (4). Nitrogen loss (Ng) in the model is measured as percentage of the total N uptake. Parameter estimates α, β_1, β_2, β_3, and β_4 have a similar interpretation and meaning as in model 4 but, for this purpose, with respect to the measure of nitrogen loss (Ng). Estimates of the parameters of this model for nitrogen gaseous losses are presented in Table 2.

Soil Erosion (Ne) – Whether by wind or water, soil erosion is often a major hazard in

Table 2. Parameter Estimates of Nitrogen Depletion Due to Gaseous Losses

Variables	Parameters	Estimate Nitrogen
Intercept	α	4.47 (5.80)
Soil fertility class (Fc)	β_1	-3.24** (0.74)
Fc x Rain (R)	β_2	-0.0004 (0.0006)
Rain (log [R])	β_3	0.77* (0.86)
Fertilizer use (Cn)	β_4	0.07** (0.02)
Statistics:		
Mean (%)		5.60
C. V. (%)		31.93
Standard error (%)		1.79
R^2 (adjusted)		0.68

**Statistically significant at 0.01 level of significance ($p \leq 0.01$).
*Statistically significant at 0.05 level of significance ($p \leq 0.05$).
$^{+}$Statistically significant at 0.10 level of significance ($p \leq 0.10$).

Standard errors are in parentheses.

Dependent variable:
Nitrogen = Amount of N gaseous losses as percent of nitrogen uptake.

agricultural lands in Africa. Wind and water erosion of soils causes about 70% of the degradation of soils. Climatic factors, topography, nutrient content of the soil, plant and litter cover, and physicochemical properties of the subsoil horizon influence erosion rates in many areas. The influence of variable rainfall in the form of high-energy storms is important in West Africa, whereas steep slopes are important in East Africa, and the presence of overused fragile soils and land clearing are widespread and important in the western semi-arid regions and in Southern Africa. All these factors help to make erosion the major process of soil fertility decline in Africa and other tropical areas (UNEP, 1991b). In addition to biophysical factors, soil erosion in Africa is also attributed to socioeconomic factors (Salako et al., 1991). Important socioeconomic factors are high population density, inappropriate and extensive land use, uncontrolled grazing with high stocking rate, and poor crop and pasture management practices.

There is abundant information in the literature on the amount of soil eroded by water in different areas and soil types of Africa (Lal, 1995a; Bishop and Allen, 1989; Lal, 1984; Charreau and Nicou, 1971; Mensah-Bonsu and Obeng, 1979; Stocking, 1986; Elwell and Stocking, 1982). Many different factors interact to determine the amount of soil loss occurring at a particular time and place. The impact of the most important factors is described by the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). Estimates of soil erosion were obtained by using the USLE and available data. This model estimates soil erosion in ton/acre/year as a function of rainfall erosivity index (R), soil erodibility factor (K), topographic factors of slope gradient and length (SL), and land cover and crop management factor (C). The cropping and management factor, C, is a composite of the effects of crops and crop sequence, tillage practices, and the interaction between these factors and the timing of rainfall through the year. Typical values for soil erosion for some African countries are summarized in Table 3.

Table 3. Selected Values of Soil Erosion Parameters in Africa

Country	Erosivity (R) (foot-ton/acre/year)	Erodibility (K)
Algeria	100-500	0.10-0.2
Angola	300-800	0.20-0.5
Botswana	300-600	0.20-0.3
Burkina Faso	200-600	0.20-0.3
Congo	400-1,000	0.30-0.6
Côte d'Ivoire	300-1,000	0.20-0.4
Egypt	60-300	0.05-0.2
Ethiopia	200-800	0.20-0.3
Ghana	300-800	0.20-0.3
Kenya	400-1,000	0.10-0.3
Lesotho	100-400	0.10-0.3
Madagascar	400-1,200	0.30-0.5
Mali	300-800	0.20-0.3
Morocco	50-300	0.10-0.2
Nigeria	400-1,000	0.10-0.4
Rwanda	500-1,200	0.30-0.5
Senegal	400-800	0.05-0.2
South Africa	200-800	0.10-0.4
Sudan	400-1,000	0.30-0.4
Tanzania	300-650	0.20-0.4
Togo	400-800	0.10-0.3
Tunisia	60-300	0.10-0.2
Uganda	300-1,000	0.20-0.4
Zimbabwe	300-800	0.20-0.4
Crop Cover and Management Factor (C)[1]		
Millet and sorghum		0.3-0.9
Cotton		0.5-0.7
Groundnuts		0.4-0.8
Cowpea		0.2-0.4
Maize		0.4-0.7
Rice (paddy)		0.3-0.5
Bare land		0.8-1.0
Supplemental (Conservation) Practices (P)[2]		
Straw mulch		0.1-0.2
Grass fallow		0.1-0.4
Contour plowing		0.4-0.8

[1]Ratio: Soil loss of crop to soil loss of fallow crop.
[2]Ratio: Soil loss of practice to soil loss of fallow crop under slope conditions.

Wind and water are natural forces that can transport soil. Erosion by wind is noticeable in the dry areas of Africa (North and sub-Saharan). The intense sand and dust storms during harmathan periods are evidence of the importance of wind erosion in North and sub-Saharan Africa. Empirical equations have been derived to estimate soil erosion caused by wind. These equations require data on wind velocity, precipitation, and moisture indices (Lal, 1985; FAO, 1976). General functional relationships between factors that affect wind erosion have been included in the wind erosion equation (Chepil and Woodruff, 1963; Skidmore et al., 1970); this equation specifies soil loss in tons/acre/year E, as a function of a soil erodibility index I, a soil-ridge roughness factor K, a climatic factor C, the field length along the prevailing wind erosion direction L, and an index of vegetative cover V.

Although wind erosion is a serious problem in many arid and semiarid zones of Africa, the equation has not yet been widely used. Data and research on wind erosion in Africa and in the tropics have been considerably less than that on water erosion.

Where reliable information was available, estimations of soil erosion by water were derived using the soil loss erosion models. Very few data were available to use the wind equation or to estimate soil erosion by wind. Enrichment values (nutrient adsorbed on soil particles) were used from empirical models and table of references to convert soil erosion losses to nutrient losses (Sobulo and Osiname, 1986; Stocking, 1986; Stoorvogel and Smaling, 1990; Vuillaume, 1982; Walling, 1984; Williams et al., 1982; Lal, 1976). Finally, estimates of nutrient losses due to erosion were obtained for country and regional levels by using the following regression function model to adjust and predict the amount of nutrient eroded (Ne):

$$Ne_i = \alpha + \delta_1 + \delta_2 + \beta_1 Fc + (\beta_2 + (\beta_3 Fc)Cn) + \varepsilon_i \quad (5)$$

where Ne_i is the percentage of nutrient loss through soil erosion in the selected crop/region; α, δ_1, and δ_2 are parameters measuring the effects of factors that are not included in the models but characterize the Sudano-Sahelian, humid, and subhumid regions, respectively. These factors characterize and are specific to each of the countries/regions. The parameters β_1, β_2, and β_3 measure the effects of the soil fertility class (Fc) and the mineral and organic nutrients applied each cropping season (Cn) on the amount of nutrient eroded. The ε_i is a random error. Parameter estimates of models used to calculate nitrogen, phosphorus, and potassium losses associated with soil erosion are presented in Table 4.

Assessment of Nutrient Inputs and Inflows

Use of Mineral Fertilizers (Mf) – Information on nutrient use (applied) per country in tons of N, P_2O_5, and K_2O was obtained from FAO database (FAO, 1996). Weight factors and GIS routines were used to calculate fertilizer use at higher levels of aggregation (by region, soil class, land use class, agroecological zone, etc.).

Use of Organic Fertilizers (Of) – The data required to calculate organic nutrient inputs mainly in the form of animal manure include the population of livestock, the amount of manure reaching arable land, and its nutrient content at the time of application. Additional information, however, is required to estimate recycling of household waste and industrial refuse. Often, some of these data are not readily available at country and regional levels.

Information from the literature on the type of manure and organic products, the rates of application by farmers, and the livestock production practices in selected regions and countries was used to estimate the amounts of nutrient inputs provided by the use of organic fertilizers. The average N, P_2O_5, and K_2O analysis of some organic fertilizers is presented in Table I.2 (Fairbridge and Finkl, 1979; Gershuny and Smillie, 1986).

Because of the low use of mineral fertilizers and the relatively high number of livestock in

Table 4. Parameter Estimates of Models of Nutrient Depletion Due to Soil Erosion

Variables	Parameters	Estimates Nitrogen	Phosphorus	Potassium
Intercept (Sudano-Sahelian)	α	18.30** (1.21)	16.20** (3.10)	20.08** (1.07)
Region (humid)	δ_1	1.75* (0.85)	-2.33* (1.33)	0.61 (0.78)
Region (subhumid)	δ_2		2.03+ (1.29)	
Soil fertility class (Fc)	β_1	-4.15** (0.76)	-2.77+ (1.82)	-4.44** (0.74)
Fertilizer use (Cn)	β_2	0.03 (0.09)	0.35+ (0.23)	-0.09 (0.20)
Fc x Cn	β_3	0.19** (0.07)	0.10 (0.17)	0.19+ (0.17)
Statistics:				
Mean (%)		15.91	18.81	14.71
C. V. (%)		15.72	18.78	14.76
Standard error (%)		2.50	3.53	2.17
R^2 (adjusted)		0.68	0.59	0.60

** Statistically significant at 0.01 level of significance ($p \leq 0.01$).
* Statistically significant at 0.05 level of significance ($p \leq 0.05$).
+ Statistically significant at 0.10 level of significance ($p \leq 0.10$).

Standard errors are in parentheses.

Dependent variables:
Nitrogen = Amount of N in eroded soil as percent of nitrogen uptake.
Phosphorus = Amount of P_2O_5 in eroded soil as percent of phosphorus uptake.
Potassium = Amount of K_2O in eroded soil as percent of potassium uptake.

some regions (Breman and Niangado, 1994), the use of animal manure in Africa is an important component of soil fertility management in some countries. Presently, average rates of application of manure by farmers using manure range from 175 to about 700 kg/ha in countries in Africa (Bationo et al., 1995). Livestock management practices vary from intensive grazing to on-the-spot feeding of livestock on crop residues. The latter is common practice in many rural areas of Africa.

Country-level estimates of the amount of nutrient returned to the soil in the form of solid manure were calculated on the basis of the amount of residue left on the field that is grazed, the nutrient content of the residue, and the fraction of nutrients from the residue that remains inside the animal. The value of this fraction used in the estimations presented in this paper was 10% as is indicated in the literature (Stoorvogel and Smaling, 1990).

Nutrient Deposition (Nd) – The amounts of nutrients that return to the soil by deposition are difficult to estimate. Deposition is associated mainly with the levels of nutrients used (and produced) and with the amount of rainfall. Wet and dry depositions were evaluated for selected sites using transfer functions. A model was estimated by using forms of empirical functions used previously in other studies (Stoorvogel and Smaling, 1990; Smaling and Fresco, 1993). In those studies, nutrient deposition in kilogram per hectare is specified as a function of the square root of average annual rainfall. Therefore, the following model was estimated and evaluated in this study:

$$Nd_i = \alpha + \delta_1 + \delta_2 + \delta_3 + \beta_1(Fc) + \beta_2(R)^{1/2} + \varepsilon_i \quad (6)$$

where Nd_i is nutrient deposition as a percentage of total nutrients, α, δ_1, δ_2, δ_3 are parameters of discrete variables included to account for variability due to regional factors, β_1 is the parameter measuring the effect of soil fertility on nutrient deposition, β_2 is the parameter measuring the effect of rainfall on nutrient deposition, and ε_i is the error term. Parameter estimates of model 6 are presented in Table 5.

Inputs of Nutrients Due to Soil Sedimentation (Ns) – This mechanism is particularly important in irrigated areas and on naturally flooded soils. Quantification is a difficult task because of the lack of sufficient information on the nutrient content of sediments. Because of this limitation, values in kilograms

Table 5. Parameter Estimates of Nitrogen Deposition Model

Variables	Parameters	Estimate Nitrogen
Intercept (arid North)	α	0.06
		(0.46)
Soil fertility class (Fc)	β_1	0.24*
		(0.14)
Region (Sudano-Sahelian)	δ_1	1.91**
		(0.35)
Region (humid-subhumid West)	δ_2	0.60+
		(0.39)
Region (subhumid East, semiarid Southern)	δ_3	0.03
		(0.32)
Rain $(R)^{1/2}$	β_2	0.065**
		(0.013)
Statistics:		
Mean (%)		2.87
C. V. (%)		19.32
Standard error (%)		0.55
R^2 (adjusted)		0.63

** Statistically significant at 0.01 level of significance ($p \leq 0.01$).
* Statistically significant at 0.05 level of significance ($p \leq 0.05$).
+ Statistically significant at 0.10 level of significance ($p \leq 0.10$).

Standard errors are in parentheses.

Dependent variable:
Nitrogen = Amount of N deposition as percent of nitrogen uptake.

per hectare per year of the amounts of nutrients in irrigation water are used for selected regions and crop systems.

Nitrogen Inputs Due to N Fixation (Nf) – Information in the literature about the nature of N uptake by crops was used to identify three basic distinctive scenarios determined by the nature of N uptake by crops:

1. About 60% of the total nitrogen uptake by leguminous crops (soybeans, groundnuts, and pulses) is supplied through symbiotic N fixation.

2. About 80% of the total nitrogen demand of wetland rice, up to a maximum of 30 kg/ha/year, is supplied through chemoautotrophic N fixation.

3. All crops benefit from N that is fixed nonsymbiotically or by N-fixing trees that are left growing in the fields. Contributions of nonsymbiotic fixation to nitrogen requirements of crops are negligible in the arid and semiarid regions. Nitrogen fixation by growing trees has been estimated to range from 2 to 10 kg N/ha, of which about 25% is expected to return to the soil.

Assessment of Nutrient Depletion and Requirements

The quantity or rate of nutrient depletion is estimated as the difference between the amount of nutrients exported annually from cultivated fields and the amount added or imported annually in the form of fertilizers, manure, fixation, and the physical processes of deposition and sedimentation. The balance of nutrient inflows and outflows (Nb_i) per year or nutrient depletion in kilograms per hectare per year for each country (i) and crop (j) is assessed and estimated as follows:

$$Nb_i = \Sigma_{ij} (Mf_{ij}, Of_{ij} Nf_{ij}) + \Sigma_i (Nd_i, Ns_i) - (\Sigma_{ij} (Nu_{ij}, Nr_{ij}) + \Sigma_i (Nl_i, Ng_i, Ne_i)) \quad (7)$$

The calculation of nutrient requirement is indicated by equation (8):

$$Nur_i = \Sigma_{ij}(Cp_{ij}) (NI_j) + \Sigma_{ij}Nr_{ij} + \Sigma_i(Nl_i, Ng_i, Ne_i) \quad (8)$$

The nutrient requirement (Nur_i) is calculated as the amount of nutrient uptake required to achieve a specific target yield without depleting the soil nutrient. The calculated nutrient uptake requirements are minimum requirements. A crop could take up more than Nur_i and this would result in increased production or yield or improved quality of the product (Driessen and Konijn, 1992). When it is necessary, the model is adjusted by the available soil nutrient content. Also, to estimate the amount of a fertilizer product required, the nutrient requirement is adjusted to account properly for the fraction of fertilizer nutrient that is actually taken up by the crop (fertilizer use efficiency).

Average rates of nutrient depletion and nutrient requirements were initially estimated at macro scale for each country in Africa (Figure 2). Because of significant variability within countries, estimates were calculated for selected areas within countries. For those areas, more elaborated transfer functions, empirical response models, and geostatistical routines were used.

Analysis of Nutrient Depletion and Requirements Under Current Crop Production

Biophysical Factors

Unfavorable climate and inherently poor soils characterize the biophysical environment of agricultural production in West African countries. The soils' natural fertility and water-retaining capacity are often low, and they are highly susceptible to wind and water erosion. The climate is highly variable and globally influenced by wind circulation patterns that determine periods of high rains, drought, and aridity in the region.

Average nutrient depletion rates as related to major soil types are presented in Figure 3. These estimates show that soils on about 23%

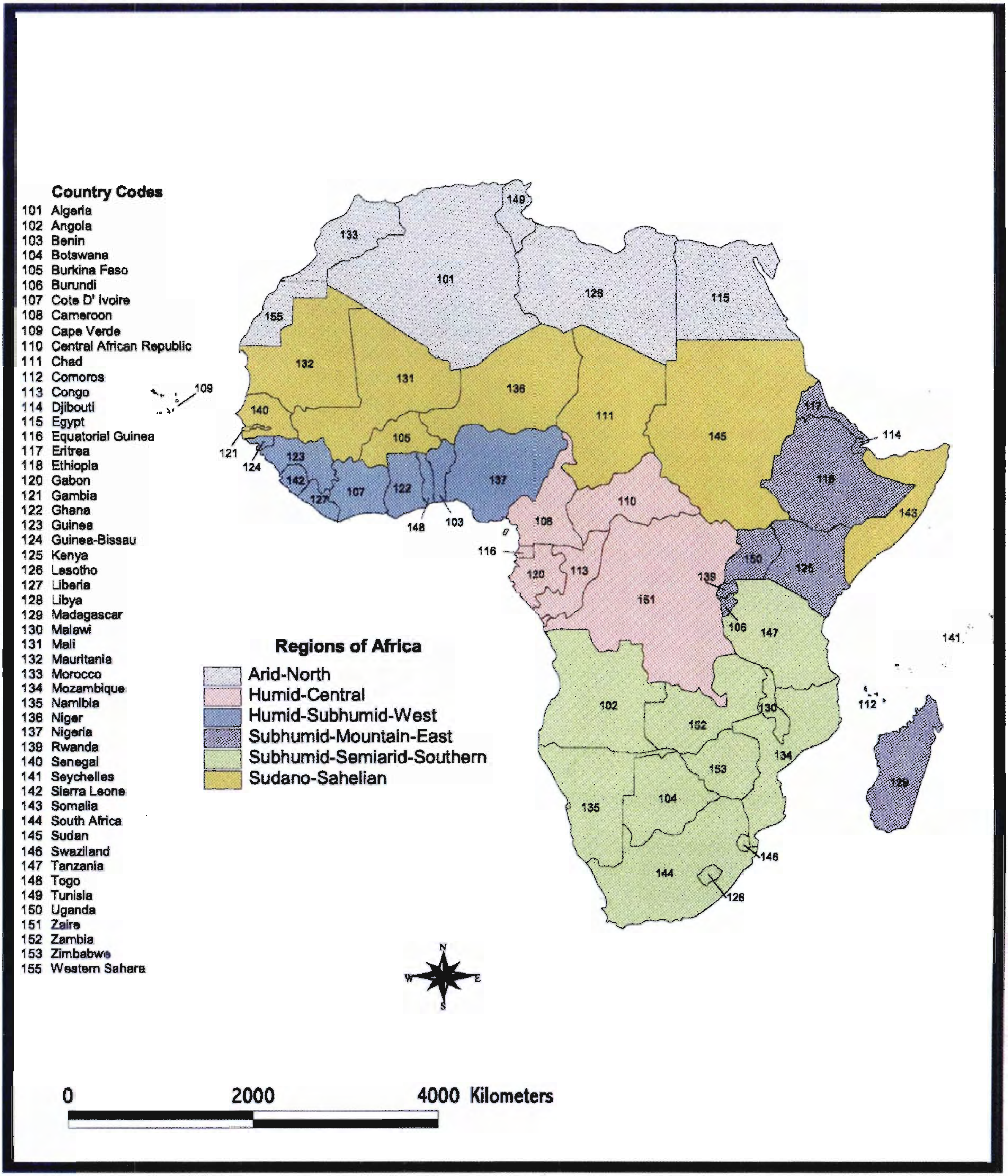

Figure 2. Countries and Regions in Africa.

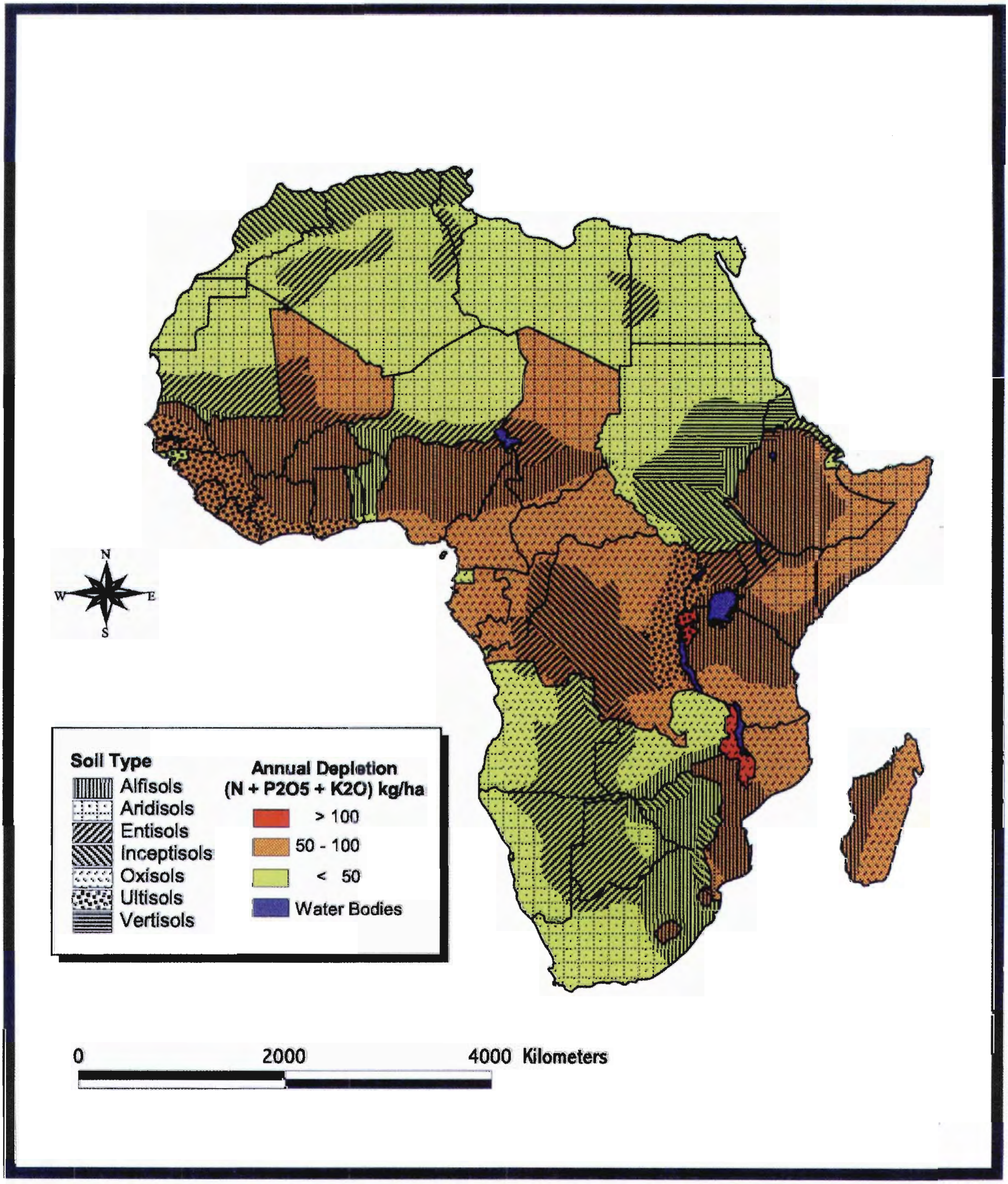

Figure 3. Average Annual Nutrient Depletion (NPK) in Soils in Africa (Years 1993-95).

of the agricultural land are classified as Alfisols (Luvisols) with nutrient depletion rates that range from 47 to 88 kg NPK/ha/year. These soils predominate in the savanna areas and at the forest-savanna boundaries of most of the subhumid and semiarid West African countries and in subhumid and semiarid East Africa principally in Ethiopia, Tanzania, Zimbabwe, Mozambique, Lesotho, and east of South Africa. These soils have low reserves of nutrients such as nitrogen, phosphorus, and zinc. In the subhumid areas, the soils occur on very weathered areas where erosion is the most serious hazard in terms of accelerated nutrient depletion and decreased productivity. In the semiarid areas, the soils are less weathered; however, moisture stress and wind and water erosion aggravated by low soil organic matter and more intensive cropping have increased the rates of nutrient depletion. Rudimentary agriculture, pastures, and some forest areas characterize most farming systems on these soils. Farmers are usually located on areas of more intensive cultivation of short-term crops with low use of external inputs such as mineral fertilizers and manure.

On about 32% of the agricultural land in Africa, soils are subject to extreme weathering; these soils have low nutrient reserves, are sequioxide-rich, and have weak retention of bases applied as fertilizers or amendments. In these areas, nutrient depletion ranges from 30 to 108 kg NPK/ha/year. These soils are classified as Oxisols (Ferralsols) and are common in areas with subsistence farming, in low-intensity grazing environments, and also in intensive plantation agriculture such as sugarcane, banana, cotton, tea, and coffee cultivation. Nutrient depletion, with significant nitrogen losses through leaching, is common in high-rainfall areas in Cameroon, Nigeria, Ghana, Tanzania, and Mozambique. Most of the Oxisols are located in humid Central Africa (Cameroon, Gabon, Equatorial Guinea, and Zaire), semiarid Southern Africa (Zaire and Angola), and subhumid and mountain East Africa (Zambia, Mozambique, and Malawi).

Agricultural production is less developed on workable Entisols (Arenosols). Most of these soils are located in the semiarid region of Southern Africa (Zaire, Angola, Namibia, and Bostwana), occupy about 9% of the agricultural land, and have nutrient depletion rates ranging from 18 to 63 kg NPK/ha/year. These soils degrade rapidly with intensive cropping. Mixed farming with cattle and sheep ranges and very low use of external inputs is the agriculture usually practiced on these soils. Other soils such as the Inceptisols occupying a small area (8%) are located in Sudan, Congo, and Zaire and in some areas in North Africa. These soils have rates of nutrient depletion that vary from 33 to 63 kg NPK/ha/year. Under appropriate management practices such as irrigation and drainage, proper crop rotation, and fertilization, the soils are highly productive. Liming and phosphate fertilization problems are acute in these soils. Acidity and phosphorus deficiency are usually the main constraints in those soils.

Ultisols (Acrisols) in some subhumid and mountain areas (9% of agricultural land) have constraints of low nutrient levels, the presence of exchangeable aluminum, and high nitrogen losses through leaching under high rainfall. Nutrient depletion rates vary from 56 to 136 kg NPK/ha/year. These soils are common in the subhumid and mountain areas in Zaire, Uganda, Rwanda, and Burundi and in the subhumid savanna areas of West Africa. Good crops are produced on these soils during the first few years, or for about the time it takes for the nutrient reserve in the organic matter to decompose and be taken up by the crop or be leached from the profile. Intensive cropping on steep lands in the subhumid and mountain areas of East Africa has led to high erosion rates. Agroforestry systems could offer alternatives for the use of these soils.

Arid soils (Aridisols-Xerosols) occupy 38% of the agricultural land in the North, the Sudano Sahelian area, and Southern Africa. The use of these soils for agriculture is severely limited by the lack of water and poor moisture retention. They are extensively used for range and seasonal grazing, except for level areas on which irrigation is practiced. In these soils, nitrogen is the most limiting nutrient. Nutrient depletion ranges from none and very low on some irrigated and well-managed soils in North Africa to high levels, about 60 kg NPK/ha/year, in other areas. Crop production on these soils in the semiarid areas is highly risky and depends mostly on irrigation and water concentrated in the river basins.

Nutrient depletion is aggravated by the climatic variability and lack of water that prevail in many countries and agroecological zones in Africa (Figure 4). This variability affects the length of growing period (LGP) or the number of days in a year during which there are both adequate moisture and suitable temperatures to support plant growth. The short length of growing periods restricts cropping systems, crops, and livestock management practices. Limited diversification of cropping systems occurs, for example, in the arid and semiarid savanna zones where the LGP is between 75 and 150 days. Soils in these areas have low inherent fertility, and their production capacity is restricted by high rates of nutrient depletion, between 30 and 80 kg NPK/ha/year. Because of the risk involved in crop production and other constraints, there is very low use of external inputs.

Arid climates with growing periods of less than 75 days dominate most of the Sudano-Sahelian regions where nutrient depletion can reach up to 70 kg NPK/ha/year. Without irrigation, the land is used for extensive grazing; however, population pressure is increasing the proportion of this land that is continuously cultivated despite the low fertility, highly variable rainfall, and high risk of erosion. In contrast, in other areas in West and Central Africa with moist climates (LGP > 270 days), excess water and high variability in soils and management systems limit yields and decrease soil fertility. The climate in more humid areas allows more diverse cropping systems. In these areas, soils have better fertility, but poor management practices and acidity are the cause of large variability in rates of nutrient depletion.

The complex interaction of climate, soils, water, and nutrient depletion largely determines crop production and resource conservation in most agroecological zones in Africa and, often, the success or failure of agricultural practices and production systems. In the semiarid areas in Africa, recycling of nutrients is low and nutrients tend to accumulate very slowly in soils under the savanna vegetation. These nutrients may be of little benefit to crops produced when the vegetation is cleared if the cropping period is very short or if it coincides with a period of drought. In the Guinea savanna zone, which lies at the border with the semiarid area and enjoys greater rainfall than the Sahelian or Sudan savanna, the rainfall is often concentrated over a few months. When this event occurs on deep soils that store more water, vigorous grasslands are supported often on more fertile and less depleted soils. The Guinea savanna merges into the derived savanna, which is followed by the drier forest, and moist, humid, and perhumid forest zones, as the rainfall and number of wet months continue to increase. As rainfall increases in these areas – more than 1,500 mm per year – the soils become increasingly acid and often depleted of nutrients.

Population-Carrying Capacity of the Land

The continued population growth and the phenomenon of migration as a result of the shortage and adequacy of land resources in Africa are important factors affecting the degradation of agricultural land. FAO estimations of the actual supporting capacity of land, calculated using crop suitability data and assuming limited use of inputs (rainfed production without mechanization, mineral fertilizers, or major conservation practices), are presented in Figure 5. The estimations of the land's supporting capacity range from less than 0.1 to 5.0 persons/ha. Thus, present rates of population density in many countries are already pressuring the land at levels that exceed the

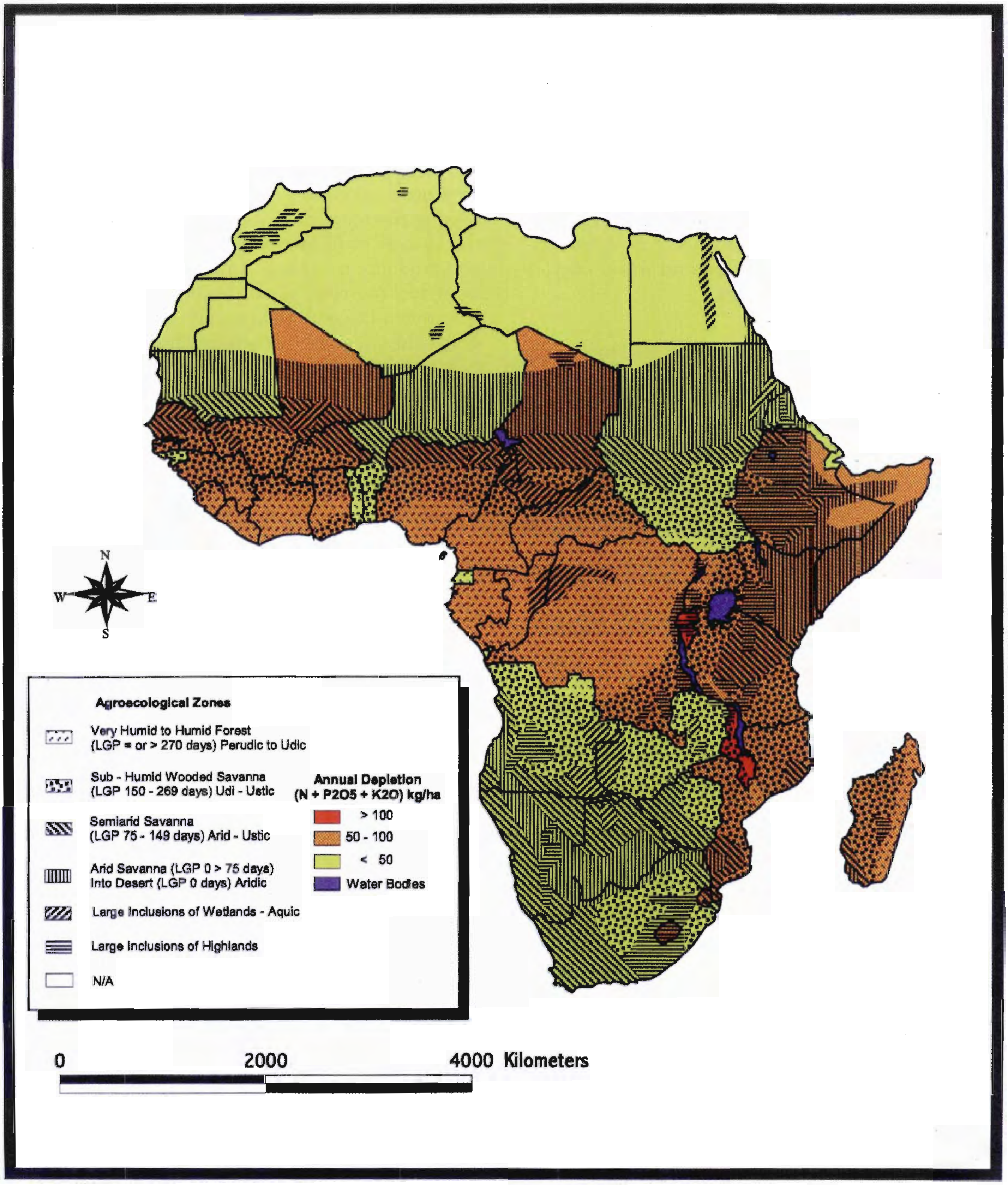

Figure 4. Average Nutrient Depletion (NPK) in Agroecological Zones in Africa (Years 1993-95).

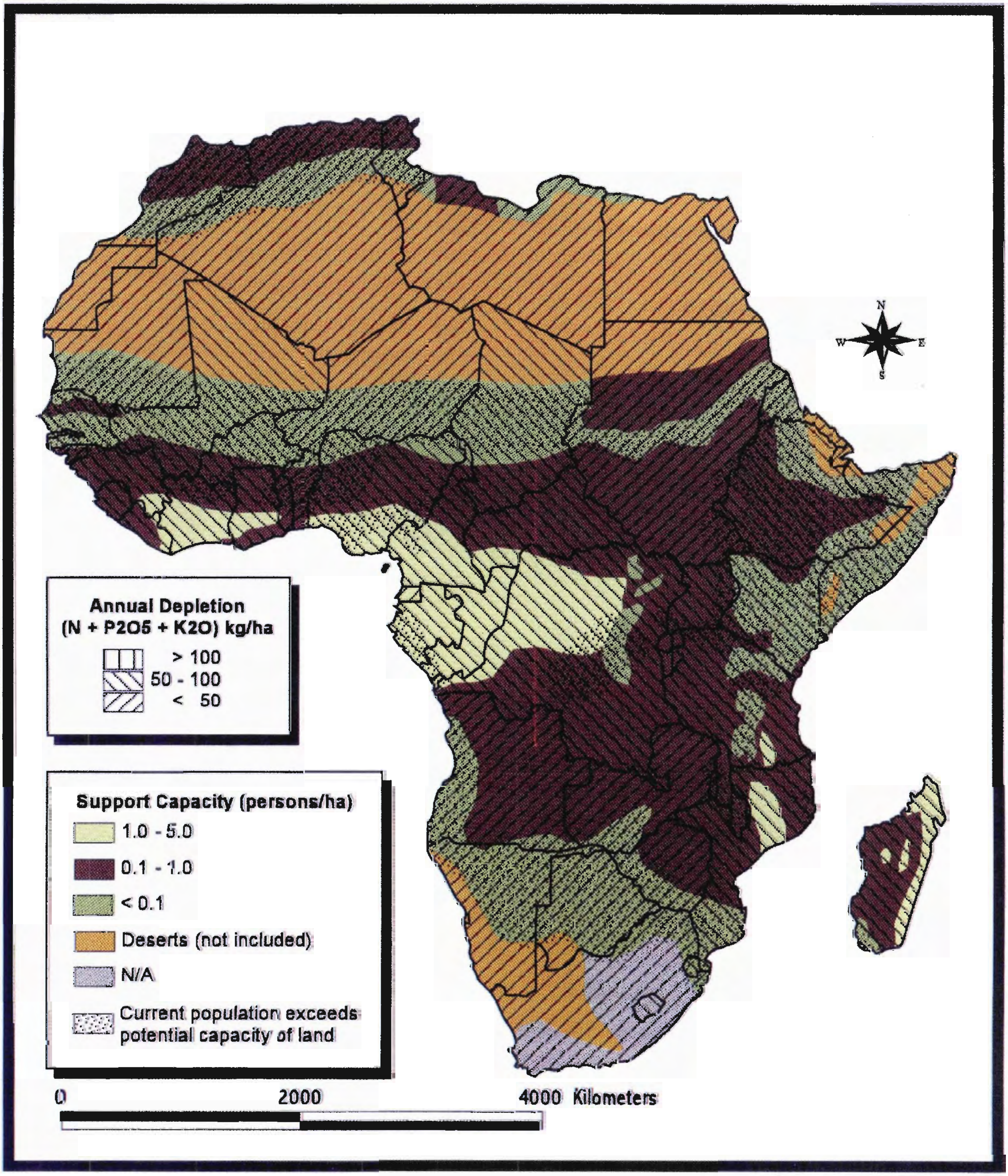

Figure 5. Average Nutrient Depletion (NPK) and Potential Population-Supporting Capacity.

long-term population-carrying capacity of that land.

The variation of population density in agricultural areas is the highest in fragile soils (Ultisols, Entisols, Alfisols, and Oxisols) in the semiarid areas of West and East Africa. In these areas population density varies from as low as 5 persons/ha in semiarid east areas to as much as 150 persons/ha in some semiarid west areas. High population densities also occur in humid and subhumid regions in the west coastal areas (Senegal, Gambia, Ghana, Togo, Nigeria, and Gabon). In some fertile east areas such as in Ethiopia, Tanzania, Burundi, Rwanda, and Malawi, the population pressure is increasing. Correspondingly, these areas have high rates of nutrient depletion.

Relative overpopulation occurs in areas where production potential is low because of climate and soil-related constraints. Soils in these areas are being overused. This has occurred on some Alfisols and Ultisols on coastal sediments in Senegal, Gambia, Togo, Benin, Nigeria, Somalia, Kenya, and Mozambique. Nutrient depletion in these areas ranges from 50 to 100 kg NPK/ha/year. Most of the rural population in the semiarid regions of West and South Africa is concentrated on coastal rivers and alluvial plains of dry savannas. The land's supporting capacity is very low (<1 person/ha), and nutrient depletion can reach 100 kg NPK/ha/year in agricultural areas in Mali, Burkina Faso, Nigeria, Ethiopia, and Kenya. In the humid and subhumid wooden savanna and forest zones in Central Africa, population per unit area is denser and more dispersed, but high concentrations are also observed in the more fertile coastal soils.

Soil degradation and nutrient depletion have been particularly severe (40 to 100 kg NPK/ha/year) in areas in the Sudano-Sahelian countries where the low supporting capacity of the land (<0.1 person/ha) has resulted in increasing cultivation of marginal lands. The land has also been subject to additional overexploitation due to deforestation and overgrazing. The use of mineral or organic fertilizers is very low, and burning of crop residues and manure for fuel is a common practice.

Very low depletion of nutrients occurs in some agricultural land areas in Libya and Egypt. In these areas the population-supporting capacity of the land is low, but there is high use of fertilizer nutrients. Humid areas with moderate nutrient depletion are located in Central Africa, Zaire, and Congo. The population-supporting capacity of these areas ranges from 1.0 to 5.0 persons/ha. However, poor infrastructure, climate, and human and animal diseases are serious constraints to the sustainable development of agriculture in these areas.

Rates of Nutrient Depletion by Country

Estimates of the amount of nutrients being depleted annually from the soils of cropland areas in each country are presented on tables in Appendix I and in Figure 6. The following observations can be drawn from these estimations:

1. Rates of nutrient depletion are, in general, very high in Africa. Annual average nutrient balances (inflows minus outflows) are negative in all countries except Mauritius, Reunion, and Libya. The nutrient balance ranges from -14 kg NPK/ha/year for South Africa to -136 kg NPK/ha/year for Rwanda in the East African region. About 96% of the countries in Africa show negative balances of nutrients that are greater than 40 kg NPK/ha/year. The total estimated annual loss (net depletion) of nutrients (NPK) amounts to about 384,800 mt, 110,900 mt, and 7,629,900 mt for North Africa, South Africa, and East and West Africa, respectively. This represents a very significant loss of the natural capital embodied in the land resources of these countries with a value estimated at US $1.5 billion per year in terms of the cost of nutrients as fertilizers.

2. On the basis of NPK balances (kg NPK/ha/year), countries can be grouped as shown on Table 6.

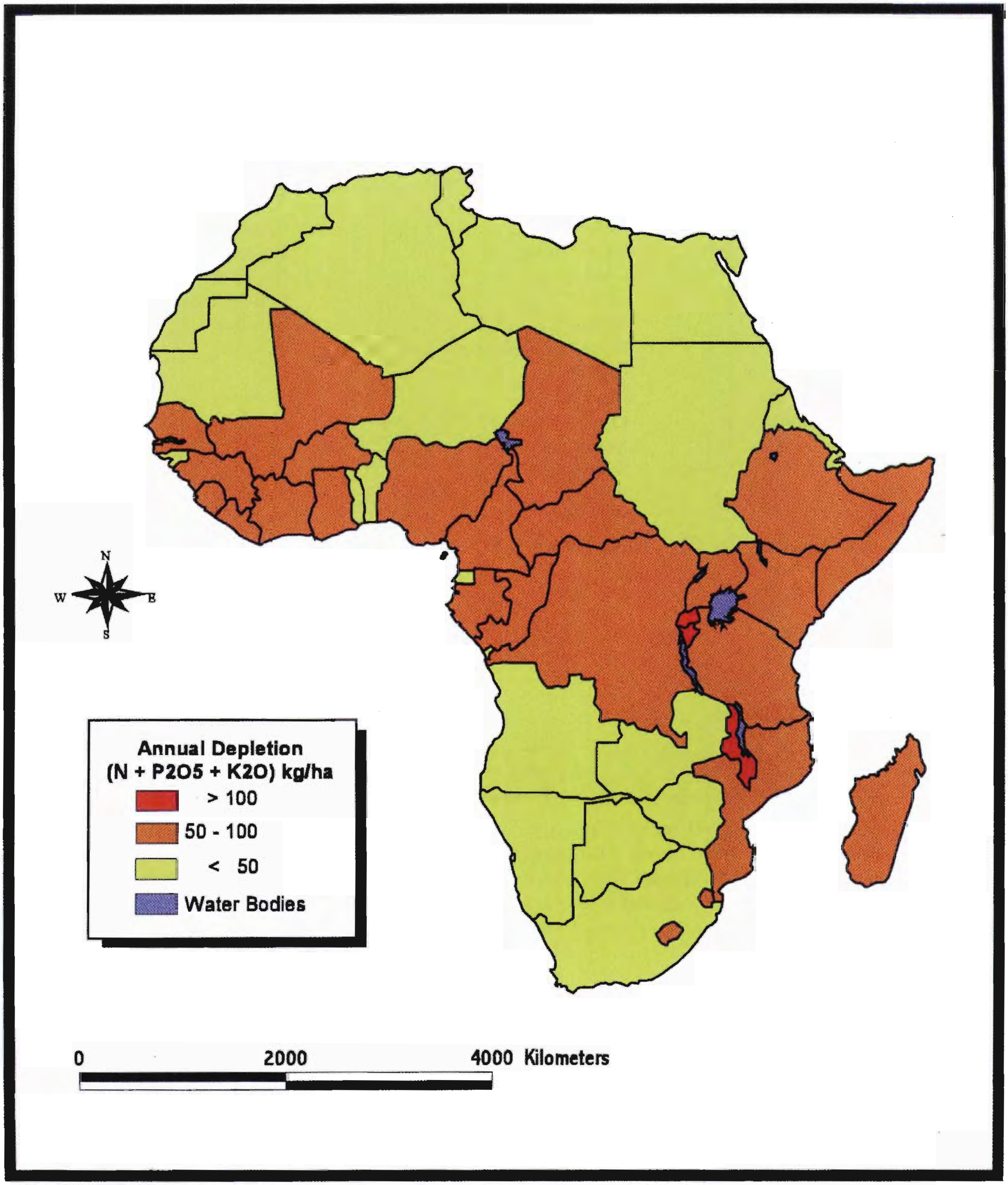

Figure 6. Average Annual Nutrient Depletion (NPK) in Africa (Years 1993-95).

Table 6. Countries Grouped by Average Level of NPK Balances (kg NPK/ha/year) in 1993-95

High	Medium	Moderate/Low
Worse Than –60 kg	Between –30 and –60 kg	Better Than –30 kg
Burkina Faso	Benin	Angola
Burundi	Cape Verde	Botswana
Cameroon	Central Africa	North African Countries
Côte d'Ivoire	Chad	South Africa
Ethiopia	Congo	Zambia
Gambia	Equatorial Guinea	
Ghana	Gabon	
Guinea	Lesotho	
Guinea-Bissau	Mauritania	
Kenya	Niger	
Liberia	Sierra Leone	
Madagascar	Sudan	
Malawi	Togo	
Mali	Zimbabwe	
Mozambique		
Nigeria		
Rwanda		
Senegal		
Somalia		
Swaziland		
Tanzania		
Uganda		
Zaire		

3. Nutrient losses are higher for nitrogen and potassium than for phosphorus. The highest depletion rates of N (greater than 35 kg N/ha/year) were found in Guinea Bissau and Nigeria in West Africa, and Burundi, Ethiopia, Malawi, Rwanda, and Uganda in East Africa. The highest depletion rates of phosphorus (greater than 15 kg P_2O_5/ha/year) were estimated for Burundi, Malawi, and Rwanda in East Africa. The highest rates of depletion of potassium (greater than 35 kg K_2O/ha/year) were found in Nigeria and Guinea Bissau in West Africa and Burundi, Malawi, Kenya, Rwanda, Swaziland, and Uganda in East Africa.

   Losses of N and K_2O are primarily associated with leaching and soil erosion and with low recycling of crop residues. Crop management systems involving the continuous cropping of cereals without rotations with legumes and without the use of proper soil conservation practices and amounts of mineral fertilizers are the major causes of N and K depletion from soils of agricultural lands in East and West Africa. Losses of P_2O_5 are associated with high erosion rates. Soil erosion is the most important factor increasing nutrient depletion in East and West African countries. Rates of soil erosion range from 10 to 120 mt/ha/year in soils of these two regions.

4. Evaluation was made of nutrient flow processes in selected soils in the present study for Rwanda (Figure 7), Mali (Figure 8), and

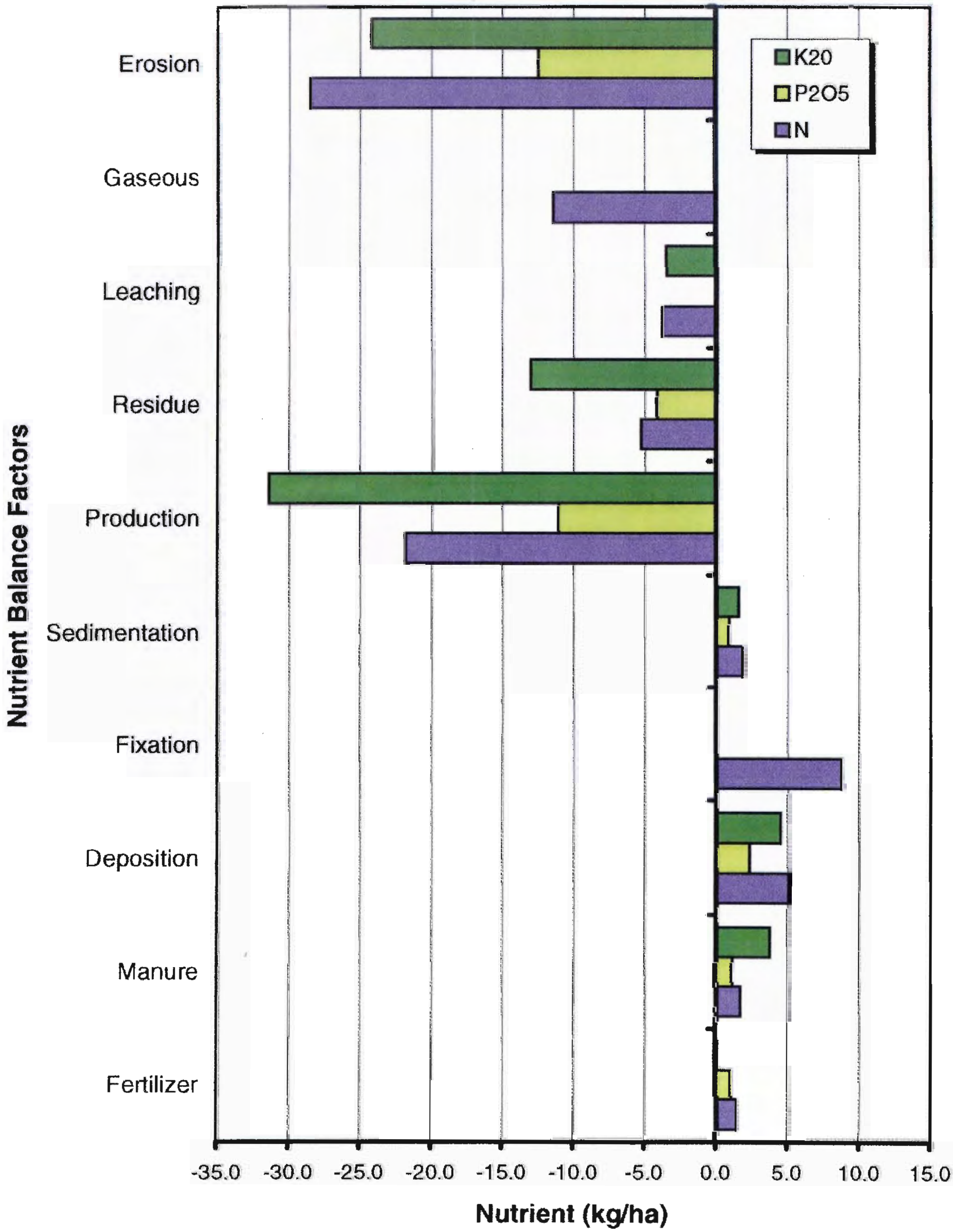

Figure 7. Nutrient Depletion Summary for Rwanda.

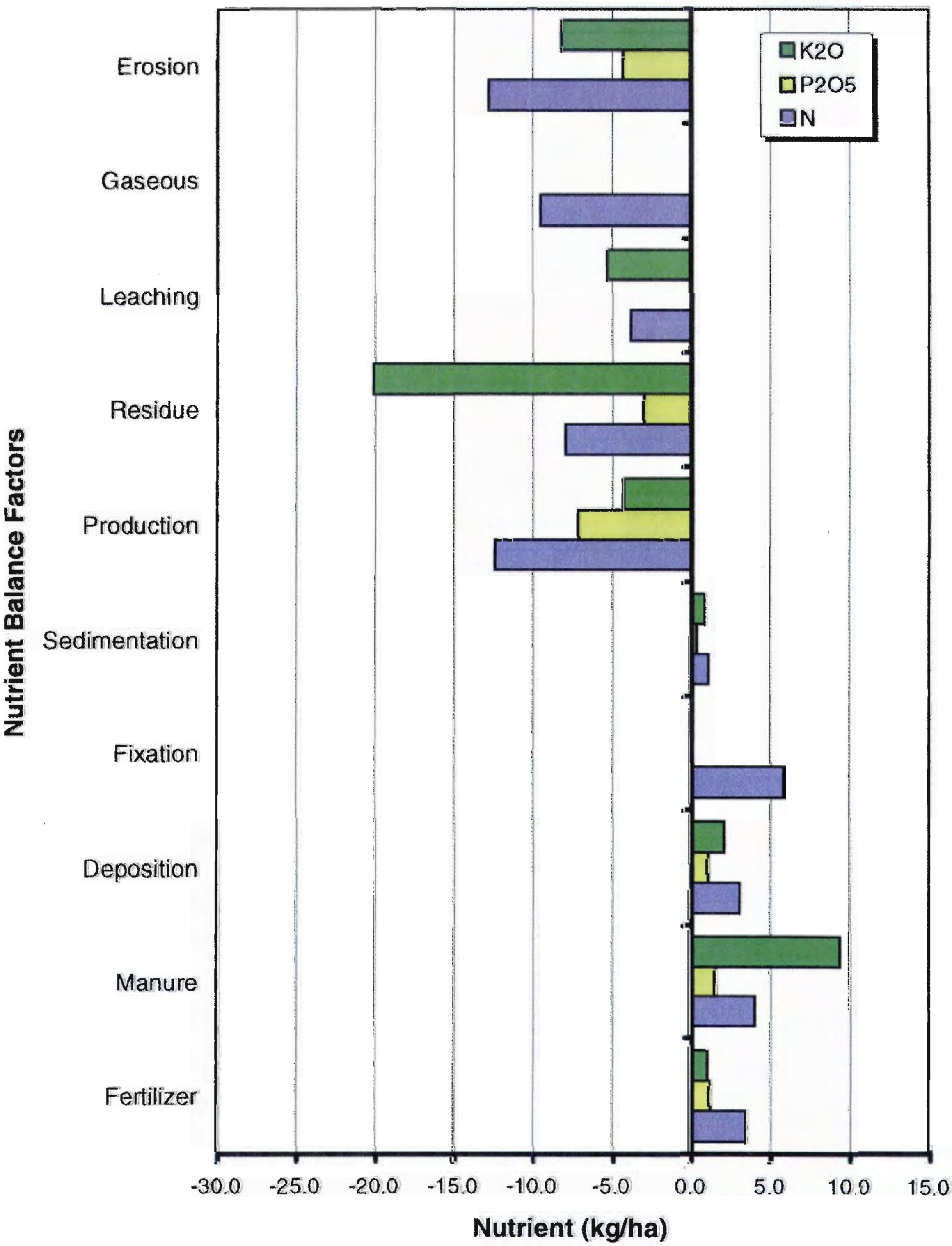

Figure 8. Nutrient Depletion Summary for Mali.

Zimbabwe (Figure 9). It is evident that soil erosion and the loss of nutrients through leaching and gaseous losses have become very serious in large segments of the semi-arid areas in West and East Africa. Unless these processes are halted through sound soil conservation and integrated nutrient management practices sustained by effective agricultural policies, other efforts to increase crop production through isolated measures such as the development of improved varieties will be of little value in reversing the trends of declining productivity in agriculture.

Nutrient Requirements, Crop Production, and Management Practices

The average use of mineral fertilizers in most countries of sub-Saharan Africa is still below 10 kg of NPK/ha (Table I.4). Fertilizer use estimates vary widely among countries, ranging in terms of quantities of NPK from nearly 234 kg/ha in Egypt to 99 kg/ha in Swaziland, 46 kg/ha in Kenya, and less than 10 kg/ha in most countries in sub-Saharan Africa. North Africa, with about 20% of the continent's surface area, accounts for about 41% of the fertilizer consumption. A few countries, i.e., Nigeria, Zimbabwe, Kenya, Sudan, and Ethiopia, account for about 75% of the total fertilizer use in sub-Saharan Africa. Fertilizer in these areas tends to be used mostly on cash and plantation crops (cacao, cotton, coffee, groundnuts, tobacco, tea, sugarcane, and oil palm). This is due to the high profitability of fertilizers in the production of export crops. Unfavorable crop/fertilizer price ratios, particularly for food crops, and financial constraints are some of the key factors explaining the current low levels of fertilizer use in food crops.

The estimates of nutrient requirements calculated in this study are based on the estimated amounts of nutrients needed to prevent nutrient depletion, assuming that current levels of crop production are maintained. Estimates of those nutrient requirements are presented in Table I.5 and Figure 10. A summary of the estimates of fertilizer requirements for the main crops in Africa is presented in Tables I.6-I.8 by region. Crop production estimates by region are presented in Tables I.9 to I.14. Some observations drawn from these estimates in regard to nutrient requirements, crop production, and management practices are presented here.

1. Africa will require approximately 11.68 million mt of NPK in fertilizers each year to maintain current average levels of production. Of this total, North Africa will require about 1,849,000 mt (15%), South Africa about 913,000 mt (9%), and sub-Saharan Africa (West and East) about 8,921,400 mt (76%) to satisfy the minimum quantity of nutrients (NPK) required for maintaining current average levels of crop production without soil nutrient depletion.

2. Average nitrogen requirements per year in North Africa range from 31.7 kg/ha in Libya to 165.1 kg/ha in Egypt. P_2O_5 requirements range from 17.1 to 37.4 kg/ha. K_2O requirements are less variable among countries, ranging from 26.4 to 36 kg/ha. The total amount of NPK required annually in North Africa ranges from 80 kg/ha in Algeria to 258 kg/ha in Egypt.

3. Nutrient requirements in South Africa essentially correspond to the amounts actually used in the country's fertilization practices. The most dramatic situation in regard to the need and importance of nutrient requirements occurs in sub-Saharan African countries. This is due to the very low fertilizer rates that are currently used in the region (Table I.4). Total nutrient (NPK) requirements per hectare per year in sub-Saharan Africa range from 24.5 kg NPK/ha in Botswana and 67.6 kg NPK/ha in Burkina Faso to 124.4 and 176.3 kg NPK/ha in Rwanda and Swaziland, respectively, in East Africa.

4. Nitrogen requirements to sustain average 1993-95 crop production per year in sub-Saharan Africa range from 11.6 kg N/ha in Botswana to 121.7 and 136.8 kg N/ha in

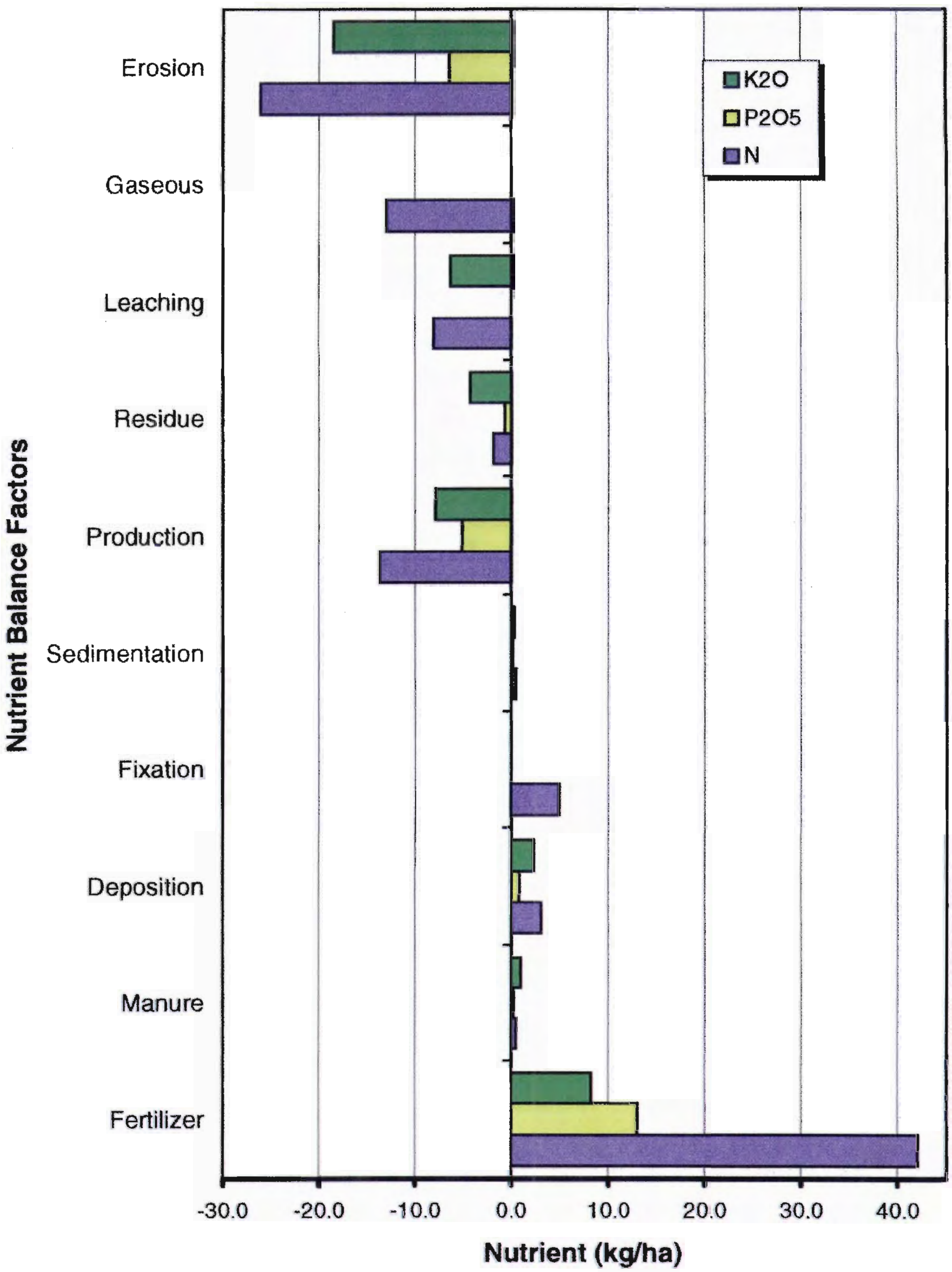

Figure 9. Nutrient Depletion Summary for Zimbabwe.

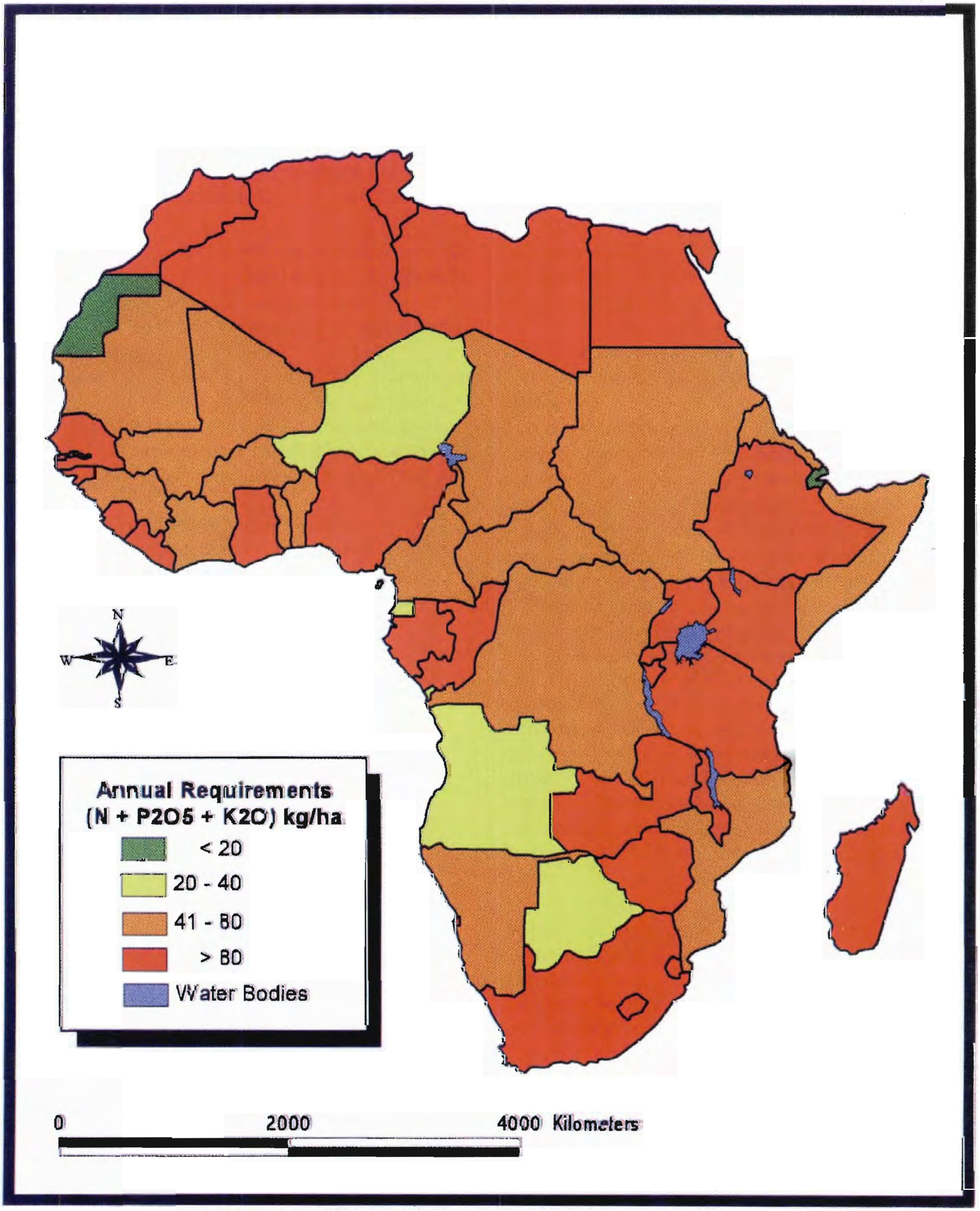

Figure 10. Average Nutrient Requirements (NPK) in Africa (Years 1993-95).

Mauritius and Reunion, respectively. Other countries with high requirements of nitrogen include Nigeria, Ghana, and Senegal in West Africa and Swaziland, Zambia, and Kenya in East Africa. P_2O_5 requirements are lower than N and K_2O requirements. The P_2O_5 requirements ranged from 5.5 kg P_2O_5/ha in Botswana and 6.6 kg P_2O_5/ha in Angola to 27.7 kg P_2O_5/ha in Uganda and 137.9 kg P_2O_5/ha in Reunion. K_2O requirements ranged from 7.4 kg K_2O/ha in Botswana to 54.7 and 69.8 kg K_2O/ha in Rwanda and Swaziland, respectively.

5. While most of the nutrient balances estimated in this study are negative, meaning that nutrients are being depleted from the soil system, nutrient requirements to cope with the nutrient depletion should not be taken as an automatic recommendation for higher doses of additional fertilizer above the basic requirements. Higher doses of fertilizer applied to less responsive local crop varieties or cropping systems will increase losses due to leaching and volatilization. Recommending more than required doses would not be a feasible solution for increasing crop production, especially in risky environments in semiarid zones and the humid areas. Rather, it is advisable to evaluate and recommend fertilizer use in conjunction with cropping systems and integrated management practices that minimize nutrient losses and increase the efficiency of the applied fertilizers (crop response).

6. Data presented in Tables I.9 to I.11 show that current aggregate levels of agricultural production increased in some countries, even in those with significant rates of nutrient depletion. These increases are mainly due to increases in land area in agriculture. Results on average yields (kg/ha of product) shown in Tables I.12-I.14 indicate that land productivity is stagnant or declining in many countries. Most yield estimates (kg/ha) are low and close to the average rainfed smallholder yields with moderate to low soil fertility. Increasing African agricultural production, without degrading land and depleting soil nutrients, will require the adoption of more productive and sound soil conservation practices and soil fertility management strategies. Such practices will require the use of mineral fertilizer nutrients and available organic fertilizers as well as the efficient recycling of nutrients.

Complementary Practices to Prevent Nutrient Depletion

Although increasing mineral fertilizer use may be the centerpiece of the technologies to balance nutrient depletion and improve soil productivity in Africa, its use must be combined with a broader spectrum of complementary technologies that increase nutrient use efficiency and prevent nutrient losses. The following are some of the technologies available:

1. The use of intercrop and crop rotation systems can help to increase nutrient pools, and the adoption of soil conservation practices can help to reduce the loss of organic matter and increase biomass production. Specific practices such as agroforestry and water harvesting (stone bunds on slopes, earth bunds) can help to reduce pressure over the land, improve soil structure, reduce runoff, and improve retention of soil moisture. Tillage practices that reduce erosion and enhance water infiltration and use of soil amendments to correct acidity in acid Ultisols and Oxisols from subhumid and humid areas are also examples of valuable complementary technologies.

2. The adoption of practices such as incorporation of crop residues, use of fodderbanks, use of grain legumes, addition of green and animal manure, use of biological nitrogen fixation, and, where possible, the improvement of fallows can contribute to soil fertility improvement. These practices can be used as components of an integrated nutrient management approach that should be tailored to the agroecological and socioeconomic circumstances of the prevailing local farming systems.

3. For many African countries, the main challenge facing agriculture is how to increase the productivity of the limited land resources that are already being degraded and in continuous use. In this context, controlling erosion and procuring irrigation and fertilizers and improved seeds are essential components of yield-enhancing technologies that can reduce the need for additional land by increasing yields and cropping intensities.

Sensitivity Analysis: Assessing Practices to Ameliorate Nutrient Depletion

As indicated previously, nutrient balances and consequently nutrient requirements are affected by biophysical (soil and climate) and management factors. It is therefore useful to evaluate a model for estimating nutrient balances in terms of its sensitivity to changes in some key factors.

A sensitivity analysis of the method and procedures used in this study was conducted using data from two countries in Africa: Mali in West Africa and Zimbabwe in East Africa. Mali is a country where erratic rainfall predominates during the cropping season, about 54% of the soils are classified as Alfisols and Aridisols (Appendix II, Table II.1 and Figure 11), and vegetation is characterized as bush and dry savanna with some intrusions of tree and wet savannas. Agricultural land in Mali has limited potential for continuous crop production without the use of appropriate management practices. Zimbabwe, located in East Africa, has a more stable subtropical climate and a type of vegetation that is characterized as bush savanna and dry forest. About 60% of the soils of agricultural lands are classified as Alfisols (Table II.2 and Figure 12) and are characterized by good drainage and soil fertility with potential for high crop yields. Levels of production of basic agricultural products in recent decades in these countries are presented in Tables II.3-II.6.

In regard to strategies to ameliorate soil depletion and restore soil fertility in the sub-Saharan zone, Van Keulen and Breman and Van der Graaf and Breman (cited by Bationo et al., 1995) concluded that increased productivity of the land, both in animal husbandry and arable farming, will require inputs from outside the system. They argue that practices such as recycling of crop residues, using on-site manure and household wastes, regeneration of degraded rangelands, and antierosion measures may at best prevent further deterioration of the land resource. On the basis of the observations made about agriculture in these two countries, the following changes in practices were included in evaluating the sensitivity of the nutrient depletion model:

1. To leave on the soil for soil conservation and grazing four different levels of crop residues – 30%, 50%, 70%, and 90%.
2. To leave on the soil about 50% of crop residue and implement other management strategies to reduce soil nutrient losses due to leaching and erosion by 20%.
3. To leave on the soil about 50% of the crop residue and reduce soil leaching and erosion losses by 40%.
4. To leave on the soil about 70% of the crop residue and reduce soil leaching and erosion losses by 40%.
5. To leave on the soil about 30% of crop residue and use crop rotation to increase nitrogen fixation and reduce nutrient losses by about 20%.
6. To leave on the soil about 30% of crop residue, use crop rotation to increase nitrogen fixation, and reduce soil losses by about 40%.
7. To leave on the soil about 50% of crop residue and improve crop rotation practices to increase nitrogen fixation.
8. To leave on the soil about 70% of crop residue and improve crop rotation practices to increase nitrogen fixation.

Results of the sensitivity analysis and evaluation are presented in Appendix III (Table III.1)

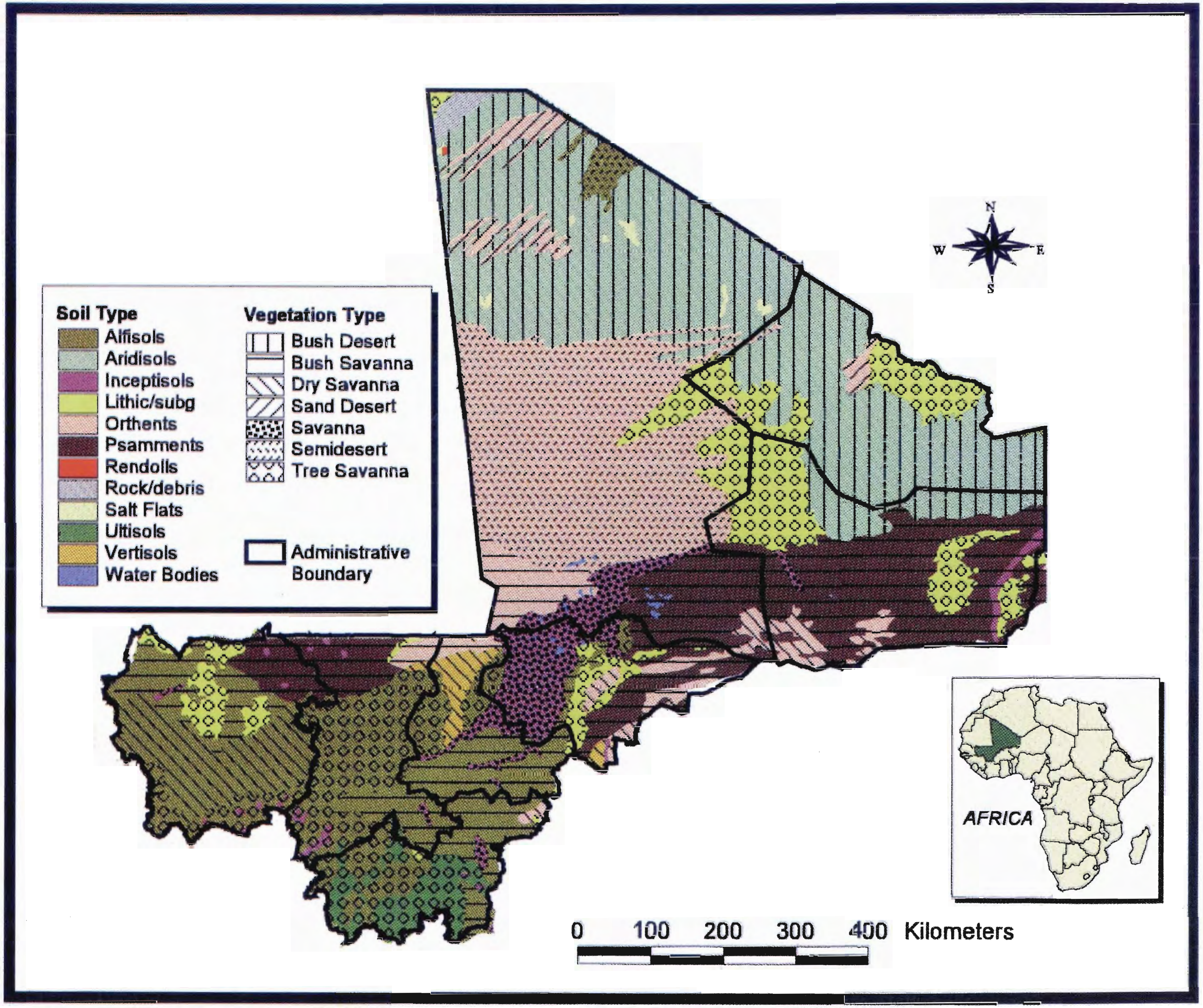

Figure 11. Mali – Soils and Vegetation.

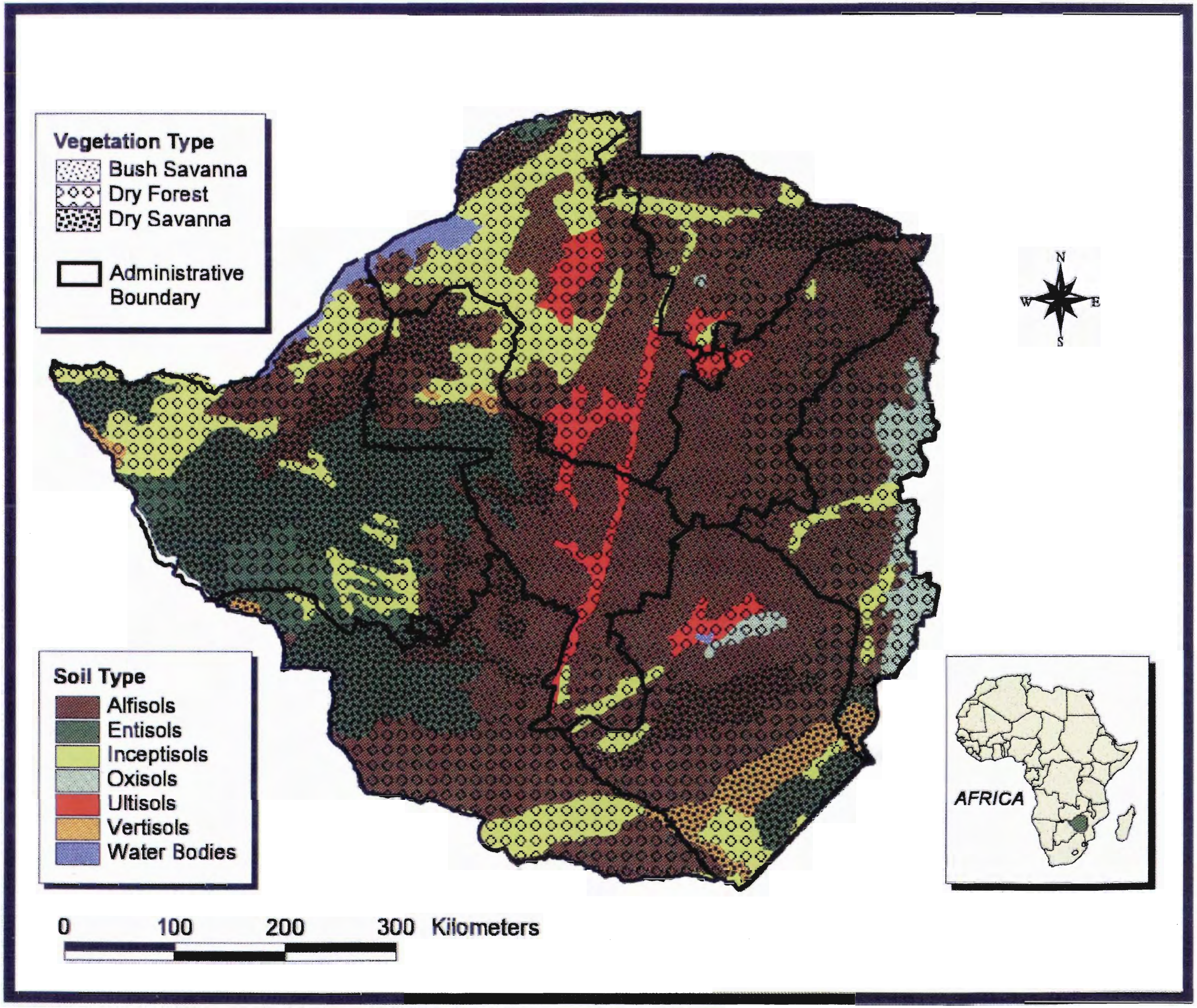

Figure 12. Zimbabwe – Soils and Vegetation.

for Mali. These results show that leaving more residues on the soil reduced nutrient depletion and decreased the need for mineral fertilizers. The practice of leaving the crop residue on the soil reduced the amount of annual nutrients (NPK) required from external sources (mineral and organic fertilizers) from 251,000 mt with 30% of residue left on the soil to 140,000 mt with 90% of residue left on the soil, about a 44% decrease in the need for the application of additional sources of nutrients.

As expected, the reduction of nutrient losses through crop management practices to control leaching and erosion losses and by using nitrogen fixation practices decreased nutrient losses significantly and reduced nutrient requirements. The practices of leaving about 70% of the residue on the soil, increasing nitrogen fixation, and reducing leaching and erosion losses by 40% can decrease the nutrient requirement by as much as 44% of what would be required using current common practices (i.e., leaving 30% of residue on soil). Similar results are observed for Zimbabwe (Table III.2). In this case, leaving 90% of crop residue on soils can reduce nutrient requirements by as much as 35% of the estimated requirements under current common practices. By leaving about 70% of crop residue on soils, increasing nitrogen fixation, and reducing nutrient leaching and erosion losses, nutrient requirements can be reduced by as much as 37%.

Estimations of the impact of crop management strategies using the soil nutrient depletion model were calculated to test the sensitivity of the model to changes in factors that affect the various components of the model. This analysis also illustrates how nutrient depletion models can be a very useful tool to evaluate and develop integrated nutrient management strategies that effectively reduce nutrient depletion. The optimum combination of practices that can be identified depends on the targets and the biophysical and socioeconomic circumstances of the particular farm area. The targets should include the levels of organic residue and crop management practices and yields that are attainable within the constraints of each farm area.

Implications for Policy Design and Development

The development and integration of databases, information systems, and models to assess the impact of various land use systems and practices on nutrient depletion and nutrient requirements have provided valuable tools for policy evaluation and development. The proper integration of data and information on land use, agricultural production, and nutrient use to evaluate agricultural production practices in the context of African agriculture has important implications for the design and implementation of policies that can promote development and also protect the environment. Some of these implications are discussed briefly in this section.

Farmers in Africa depend on the land for their livelihood and are currently facing the depletion of nutrients and degradation of their limited land resources. They have very limited access to information and usually no incentives to increase production and preserve the environment.

In many of the agricultural areas, stagnant crop production and nutrient mining have a reinforcing effect that traps African agriculture in a downward spiral. The symptoms appear throughout the farming regions – erosion, deforestation, soil compaction and waterlogging, nutrient depletion, and desertification. While agricultural land is being seriously degraded, African populations continue to increase and demand more food and services. Migration to urban areas is increasing and is becoming an increasingly dangerous threat to food security and social and political stability. If nutrient depletion and land degradation continue at current rates, one has to wonder how farmers in African countries will be able to have productive land and grow enough food for the increased population in the next century.

National governments and donors should address the threat of nutrient depletion and land degradation through policies and information services that promote increased productivity of land resources and conservation of the resource base. There is a need in many countries and regions to face the challenge of integrating natural resource management with economic and sector policies. More economic and environmental impact analyses at the country level will be needed to set priorities on agricultural land issues, assess the costs and benefits of policy decisions, and expedite the identification of the type of investments that will be required to prevent land degradation and increase production. Prevention of nutrient mining through sound economic policies, research, information dissemination, and human resource development should be actively promoted in these countries.

It is important to recognize that technical change cannot and will not be implemented unless far-reaching policy changes are introduced by African governments. Some options open to the governments are as follows:

- Development of national and regional action plans to increase land productivity and crop production on a sustainable basis using available technology. Given the present circumstances of many countries in Africa, increasing agricultural production requires rapid growth in the use of mineral fertilizers as part of an integrated approach to the management of nutrients and land and water resources.
- The creation of an institutional framework to address issues of land tenure policies and the efficiency of land and water markets and to promote the adoption of strategies for preventing land degradation. Policies should facilitate the increased and judicious use of external inputs such as mineral fertilizers and the development of long-term management practices to increase productivity and conserve land resources. This will also help to reduce population migration and pressure on forest, rangeland, and marginal lands.
- Promotion of research and development to adopt promising technologies and support the exchange of appropriate technology. Advice to farmers should take advantage of the progress achieved in similar agroecologies as well as promising agricultural practices for the region.
- Promotion and support of extension services, local farmer organizations, and non-governmental organizations as key participants in programs to educate farmers about nutrient depletion, its consequences, and prevention. A suitable approach for solving agricultural land degradation problems can be found by identifying target groups and their specific needs and cooperating with them in designing ways to combine modern technologies with traditional knowledge.
- Development of rural and urban agricultural credit systems and efficient markets for agricultural products that (a) assist the development of effective agricultural production plans and improve market strategies and intraregional trade and (b) promote crop diversification and improve domestic and export market structures and market information. In the semiarid areas of Africa, regional trade is usually induced more by resource complementarity than by coherent policies supporting regional markets.
- Implementation of sound policies that promote environmental awareness and land conservation and that increase agricultural production. It has been pointed out that the structural adjustment programs (SAP) implemented in some countries have contributed to increased land degradation. There are also indications that expenditures in agricultural programs to prevent land degradation have been reduced and that poor policy decisions to restrict trade and maintain low prices for agricultural products have contributed to increases in unemployment and have forced rural people to encroach upon marginal lands. This in turn has helped to escalate the exploitation of natural resources, leading to deforestation, intensive monoculture cash crops, destruction of wetlands, and water pollution.

In view of the magnitude of nutrient depletion from soils of agricultural lands in many countries of Africa and its associated impact on land degradation, there is an urgent need to reverse this process. In this context, measures providing incentives for farmers and communities to implement integrated nutrient management programs involving the use of mineral fertilizers must be taken as part of action programs to promote rural development and resource conservation. Such measures may include the following:

- Establishing efficient and effective systems to supply fertilizers, seeds, and other agri-inputs. These systems remain underdeveloped in many countries due to the small size of the market, limited technical know-how of dealers, poor information network systems, and lack of a regulatory framework for quality control. Because most countries will continue to depend on imports to satisfy fertilizer needs, national governments and donors should work together to ensure an adequate and timely supply of foreign exchange and to guarantee the supply of credit funds for the import and domestic marketing and sale of fertilizers. Given the small size of the market for fertilizers in many countries, care should be taken to ensure that competition in the market is maintained and that public monopolies are not replaced by private monopolies. To keep prices affordable for farmers, no tariffs or taxes should be levied on import, production, or sale of fertilizer.
- Supporting the availability of credit to finance the efficient procurement, distribution, and retailing of fertilizers.
- Strengthening input delivery systems by creating dealer networks that include private traders and farmer organizations; these networks should function within the proper regulatory framework and should have access to adequate information to promote competition.
- Improving transport and communication infrastructure such as roads, rail ports, and the communication systems.

Applying the necessary preventative and corrective measures on soil nutrient mining and land degradation to achieve balance between conservation and development on a sustainable basis requires a careful approach. National governments must draw on an array of sound policies and strategies that should be formulated in discussions with community representatives and that embrace both incentive and regulation. However, irrespective of these initiatives, it is the land user/owner who must be trained and informed and who must ultimately accept the responsibility for achieving ecologically sustainable production and development.

In regard to implications for information gathering and processing, it is important to recognize that although the processes underlying most forms of nutrient depletion seem reasonably well understood, and there is increased interest in establishing the links between these processes and the climate and management practices, land nutrient resources continue to be degraded. It has been suggested that part of the problem lies in the inadequacy of information available to managers, policymakers, and researchers, particularly regarding the complexities of environmental interactions that result from changes in land characteristics and use. In this context, it should be noted that the formulation of effective strategies to prevent nutrient depletion and land degradation requires information at different levels:

- Inventory and mapping of landscape parameters: soil (characteristics and potential, fertility, constraints, erosion and land degradation, moisture, land quality); vegetation (crops, zones, agroforestry); climate (rainfall, temperature, climate zones); market infrastructure (roads, regional crop and livestock production, agricultural constraints, and irrigation); and land use patterns.
- Monitoring of the nature and rate of changes in crop and land management, production, fertilizer use, price changes, and population growth, density, and structure.
- Prediction of the effects of changes in soil nutrients, crop production, and land use.

Inventory and mapping are required to define the current status of the resource base and provide a baseline for monitoring. Changes to soils and land conditions, which are management-driven, must be distinguished from natural or background changes; thus, the methodology for effective monitoring of nutrient depletion and land degradation must take into account processes that occur across space as well as time, and surveys for data gathering that must be repeatable and comparable. Predictive modeling requires a thorough understanding of the current status of land use and soil processes and the ability to extrapolate, both spatially and temporally, using models that capture the complex interactions between soil elements and their response to changes in management. A combination of real-time monitoring and simulation of soil properties and plant growth supported by weather forecasting appears to offer the most effective way to predict expected changes in soil conditions and nutrient depletion.

Information is required at different scales – nationally, regionally, and at the farm level – to facilitate policy actions and evaluation. Land resource base planning and monitoring initiatives should involve the efficient exchange of data among various institutions engaged in the gathering and processing of relevant data.

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Appendix I

Table I.1. Nutrient Uptake by Product and Residue of Main Crops

Crop	N Product	N Residue	P_2O_5 Product	P_2O_5 Residue	K_2O Product	K_2O Residue
	(kg/mt)					
Alfalfa (Lucerne)	26.0	0.0	7.2	0.0	18.0	0.0
Almonds	14.6	6.6	6.1	1.7	6.7	7.9
Apples	1.0	1.1	0.5	0.2	1.9	2.8
Apricots	4.1	1.6	1.3	0.8	6.3	6.3
Artichokes	3.4	1.4	1.2	0.8	3.7	1.3
Avocados	3.4	0.8	2.0	0.3	7.0	1.8
Bananas	2.3	2.5	0.9	0.7	8.6	12.0
Barley	15.8	6.3	5.8	1.8	8.3	20.6
Cabbages	5.4	3.2	1.8	0.9	8.0	2.6
Cantaloupes	2.8	1.0	1.2	0.6	3.7	1.2
Carrots	3.5	1.5	1.2	0.8	4.1	1.3
Cashew nuts	14.6	6.6	6.1	1.7	6.7	7.9
Cassava	2.8	3.9	1.1	1.8	3.1	2.4
Castor beans	36.8	34.2	10.1	5.6	8.4	11.2
Cauliflowers	5.4	3.2	1.8	0.9	8.0	2.6
Chestnuts	14.6	6.6	6.1	1.7	6.7	7.9
Chick peas	20.3	10.4	7.8	2.3	13.5	15.7
Citrus n.e.s.	1.4	0.8	0.5	0.5	2.8	2.3
Cocoa beans	35.0	12.3	12.8	8.5	17.7	37.1
Coconuts	55.0	23.0	15.9	13.1	11.8	30.4
Coffee	30.5	4.3	5.6	8.7	24.0	11.1
Cucumbers, etc.	2.4	1.2	1.1	1.0	3.8	0.8
Currants	4.0	1.8	0.9	0.5	8.6	5.8
Dates	2.6	1.4	0.9	0.5	4.6	3.9
Dry beans	17.8	10.0	9.4	3.1	15.1	16.9
Dry broad beans	17.8	10.0	9.4	3.1	15.1	17.3
Dry onions	3.2	1.2	1.2	0.9	3.2	1.1
Dry peas	20.5	10.3	9.6	3.1	15.1	16.9
Eggplants	2.4	1.2	1.1	0.8	3.8	1.1
Flax fiber	12.6	2.5	6.1	1.3	13.3	2.8
Garlic	3.3	1.2	1.2	0.9	3.2	1.2
Grapefruit & pomelo	1.8	1.4	0.5	0.5	3.6	3.9
Grapes	3.7	1.8	1.4	0.5	5.9	4.1
Grass/Clover	25.0	0.0	7.5	0.0	30.0	0.0
Green maize	3.0	0.0	1.1	0.0	3.6	0.0
Green beans	8.6	2.3	1.5	1.1	6.9	3.8
Green peas	8.6	2.3	1.3	1.1	5.7	3.8
Green peppers	4.3	1.8	1.2	0.9	3.2	3.2
Groundnuts	34.5	12.4	13.5	7.6	8.3	19.3
Hazelnuts	14.6	6.6	6.1	1.7	6.7	7.9
Hemp fiber	18.6	1.3	6.2	0.6	11.5	1.1
Hempseed	6.6	6.5	3.1	4.1	8.3	11.2
Hops	17.8	12.0	4.5	4.5	10.1	9.6
Jute/jute-like fibers	22.3	1.4	11.8	0.7	34.3	1.6

(continued)

Table I.1. Nutrient Uptake by Product and Residue of Main Crops (continued)

Crop	N Product	N Residue	P_2O_5 Product	P_2O_5 Residue	K_2O Product	K_2O Residue
	(kg/mt)					
Lemons	2.1	1.4	0.9	0.5	4.6	3.9
Lentils	20.0	10.4	7.8	2.3	13.5	15.7
Linseed	40.0	34.6	10.1	5.6	8.4	11.2
Maize	16.1	11.9	6.3	4.4	4.8	17.3
Mangoes	2.4	1.4	0.8	0.5	3.8	3.9
Millets	17.4	6.5	8.7	8.8	6.5	21.8
Oats	16.7	9.4	7.9	2.5	9.2	20.5
Olives	33.4	28.4	10.1	5.6	9.6	14.2
Oranges	2.4	1.3	0.9	0.5	4.8	3.9
Palm kernels	2.9	4.1	1.6	1.4	4.9	5.5
Papayas	2.1	1.4	0.9	0.5	4.6	3.9
Peaches	3.2	1.4	1.2	0.5	4.6	3.9
Pears	2.6	1.4	0.9	0.5	4.6	3.9
Pineapples	3.7	4.6	1.0	0.5	7.1	4.1
Pistachios	14.6	6.6	6.1	1.7	6.7	7.9
Plantains	2.3	2.5	0.9	0.7	4.1	7.7
Plums	3.2	1.6	1.2	0.8	4.6	3.9
Potatoes	4.4	2.3	3.0	1.6	8.3	5.4
Pumpkins, etc.	2.4	1.2	1.1	0.8	3.8	1.1
Rape seed	36.8	34.2	10.1	5.6	8.4	11.2
Raspberries	2.6	1.4	0.9	0.5	4.6	3.9
Rice-paddy	14.6	7.6	6.0	3.0	3.2	20.5
Rubber natural	7.5	1.5	2.9	0.5	7.2	4.8
Rye	16.3	7.5	8.3	2.5	8.4	20.5
Safflower seed	32.6	34.2	9.8	5.6	7.6	11.2
Seed cotton	26.7	23.3	22.5	6.7	10.0	23.3
Sesame seed	33.4	14.2	10.1	5.6	9.6	11.2
Sisal	22.3	1.8	6.8	0.7	11.8	1.1
Sorghum	15.3	10.2	7.5	3.8	3.8	18.2
Soybean	62.1	13.3	13.2	3.0	24.0	21.2
Strawberries	3.3	1.4	1.5	0.5	4.3	3.9
Stylosantes	28.5	0.0	7.0	0.0	16.5	0.0
Sugar beets	2.0	1.5	0.7	0.5	4.5	1.6
Sugar cane	1.0	1.5	0.5	0.3	2.4	1.6
Sunflower seed	40.0	35.0	12.3	6.2	6.8	11.0
Sweet potatoes	3.9	2.5	1.8	1.7	7.6	4.9
Tang. mand. clementines	2.1	1.4	0.9	0.5	3.8	3.2
Taro	3.5	4.1	1.6	1.0	4.2	5.3
Tea	35.0	0.3	11.5	0.1	24.0	0.5
Tobacco leaves	50.3	0.3	16.8	0.1	65.0	0.5
Tomatoes	2.8	1.4	0.7	0.7	3.8	1.2
Walnuts	14.6	6.6	6.1	1.7	6.7	7.9
Watermelons	2.6	1.1	1.4	0.8	3.8	1.1
Wheat	22.3	6.4	11.1	2.8	5.6	24.2
Yams	3.0	1.9	1.1	1.1	4.2	3.7

Note: 0.0 = very small negligible amounts.

Table I.2. Average Composition of Some Natural Organic Materials

Organic Material	Composition (% by weight)						
	N	Sd	P_2O_5	Sd	K_2O	Sd	H_2O
Animal wastes (% of fresh material)							
Farmyard manure	1.15	0.7	0.48	0.4	0.90	0.4	70
Dairy manure	2.10	1.4	0.60	0.3	1.65	0.6	80
Goat manure	2.80	1.8	0.63	0.4	2.40	1.2	60
Sheep manure	2.00	1.4	0.45	0.3	2.10	1.6	60
Poultry manure	1.60	1.2	0.85	0.7	1.00	0.7	60
Pig manure	0.60	0.4	0.32	0.2	0.35	0.2	75
Horse manure	0.70	0.5	0.15	0.1	0.45	0.3	60
Urban wastes (% of fresh material)							
Activated sewage sludge	5.60		2.50		0.30		
Digested sewage sludge	2.00		0.50		0.30		
Miscellaneous (% of dry material)							
Tobacco stems	1.50		0.20		4.20		
Fish scrap (acidulated)	5.70		1.30				
Fish scrap (dried)	9.50		2.60				
Bone meal (raw)	3.50		19.80				
Bone meal (steamed)	2.00		12.20				
Cocoa shell meal	2.50		0.40		2.50		
Peanut hull meal	1.20		0.20		0.70		

H_2O = % of moisture.
Sd = Estimated standard deviation (average value +/- Sd).

Table I.3. Annual Nutrient Balance in Africa – 1993-1995

Country	NPK	N	P_2O_5	K_2O	NPK
	('000 mt)	------------ (kg/ha)			--------------
North Africa					
Algeria	-79.6	-8.9	-3.7	-20.7	-33.3
Egypt	-92.1	20.2	-11.0	-33.2	-24.0
Libyan Arab Jamahiria	32.1	14.4	65.5	-21.3	58.6
Morocco	-196.3	-11.0	2.1	-25.3	-34.2
Tunisia	-48.9	-11.8	10.0	-34.6	-36.4
Subtotal	-384.8				
South Africa	-110.9	-7.3	14.7	-21.5	-14.1
Sub-Saharan Africa					
Angola	-57.6	-14.1	-2.9	-13.4	-30.4
Benin	-62.8	-22.7	-5.5	-18.4	-46.6
Botswana	-2.8	-9.0	-1.4	-7.8	-18.2
Burkina Faso	-216.5	-27.6	-9.8	-24.2	-61.6
Burundi	-92.1	-45.0	-15.4	-53.0	-113.4
Côte d'Ivoire	-338.3	-26.8	-9.7	-24.7	-61.2
Cameroon	-145.9	-28.0	-8.9	-26.2	-63.1
Cape Verde	-1.7	-28.0	-7.9	-16.7	-52.6
Central African Republic	-27.0	-21.2	-12.6	-16.7	-50.5
Chad	-105.9	-22.5	-13.5	-17.0	-53.0
Comoros	-1.0	-34.5	-	-	-34.5
Congo	-11.0	-22.7	-11.6	-21.1	-55.4
Equatorial Guinea	-2.2	-15.7	-5.2	-	-20.9
Ethiopia	-522.4	-35.5	-13.2	-38.9	-87.6
Gabon	-6.7	-21.4	-7.8	-20.9	-50.1
Gambia	-10.3	-29.9	-10.8	-21.9	-62.6
Ghana	-273.2	-39.2	-14.1	-26.2	-79.5
Guinea	-56.5	-33.1	-10.6	-24.9	-68.6
Guinea-Bissau	-12.7	-38.7	-9.5	-36.1	-84.3
Kenya	-194.0	-41.8	-1.3	-35.3	-78.4
Lesotho	-7.1	-36.7	9.5	-25.6	-52.8
Liberia	-11.0	-31.5	-7.2	-22.7	-61.4
Madagascar	-151.1	-26.5	-13.8	-25.4	-65.7
Malawi	-220.8	-47.5	-16.0	-45.3	-108.8
Mali	-204.3	-29.4	-7.3	-24.2	-60.9
Mauritania	-14.8	-19.7	-8.4	-26.0	-54.1
Mauritius	-181.0	-30.4	-10.1	-22.6	-63.1
Mozambique	0.4	13.8	1.3	-10.0	5.1
Niger	-351.8	-20.8	-7.7	-19.2	-47.7
Nigeria	-2,246.4	-36.2	-10.6	-39.8	-86.6

(continued)

Table I.3. Annual Nutrient Balance in Africa – 1993-1995 (continued)

Country	NPK	N	P_2O_5	K_2O	NPK
	('000 mt)	(kg/ha)			
Sub-Saharan Africa (continued)					
Reunion	0.3	17.1	8.2	-15.9	9.4
Rwanda	92.1	-51.4	-22.6	-62.4	-136.4
Senegal	-143.3	-31.6	-8.2	-26.9	-66.7
Sierra Leone	-27.5	-26.2	-6.8	-23.1	-56.1
Somalia	-70.8	-37.3	-12.7	-32.9	-82.9
Sudan	-408.7	-14.4	-6.0	-17.5	-37.9
Swaziland	-11.2	-37.2	-5.9	-46.8	-89.9
Tanzania United Republic	-434.9	-37.4	-13.7	-30.0	-81.1
Togo	-57.7	-21.2	-7.9	-19.8	-48.9
Uganda	-324.6	-38.1	-12.2	-37.5	-87.8
Zaire	-379.4	-27.9	-10.8	-24.2	-62.9
Zambia	-32.8	-12.6	-2.9	-14.5	-30.0
Zimbabwe	-118.7	19.8	-1.7	-25.5	-47.0
Subtotal	-7,629.9				
Total	-8,125.6				

Note: Dash (-) = no data available.

Table I.4. Annual Nutrient Consumption in Africa – 1993-1995

Country	Area	NPK	N	P_2O_5	K_2O	NPK
	('000 ha)	('000 mt)	- - - - - - - - - - - (kg/ha)- - - - - - - - -			
North Africa						
Algeria	2,389	116.9	25.9	14.3	8.7	49
Egypt	3,839	900.0	201.6	26.4	6.4	234
Libyan Arab Jamahiria	548	87.3	46.2	106.1	6.9	159
Morocco	5,739	305.4	25.1	18.3	9.8	53
Tunisia	1,343	96.8	37.7	32.3	2.1	72
Subtotal	13,858	1,506.4				
South Africa	7,867	803.0	49.6	36.1	16.4	102
Sub-Saharan Africa						
Angola	1,894	9.0	1.2	1.9	1.6	5
Benin	1,347	16.5	5.4	4.4	2.5	12
Botswana	154	1.0	2.6	2.6	1.1	7
Burkina Faso	3,514	21.9	2.8	2.3	1.1	6
Burundi	812	4.0	1.7	3.0	0.2	5
Côte d'Ivoire	5,528	57.5	5.7	1.8	3.0	10
Cameroon	2,312	23.9	5.5	1.9	3.0	10
Cape Verde	33	0.0	0.0	0.0	0.0	0
Central African Republic	534	1.2	1.8	0.2	0.2	2
Chad	1,999	7.4	1.4	1.0	1.3	4
Comoros	28	0.1	3.6	-	-	4
Congo	199	2.0	5.0	0.0	4.9	10
Equatorial Guinea	105	0.0	0.0	0.0	-	0
Ethiopia	5,964	62.3	3.7	6.7	0.0	10
Gabon	134	0.4	0.7	0.7	1.7	3
Gambia	164	0.8	1.2	2.4	1.2	5
Ghana	3,436	9.2	1.7	0.7	0.3	3
Guinea	823	1.1	0.9	0.2	0.2	1
Guinea-Bissau	151	0.4	0.7	1.2	0.7	3
Kenya	2,474	113.7	20.2	22.8	3.0	46
Lesotho	134	5.9	6.7	29.9	7.5	44
Liberia	179	0.0	0.0	0.0	0.0	0
Madagascar	2,300	10.0	2.3	0.9	1.2	4
Malawi	2,029	61.4	18.9	8.4	3.0	30
Mali	3,355	22.9	3.4	2.5	0.9	7
Mauritania	273	5.3	17.3	2.1	0.0	19
Mauritius	81	27.3	135.4	44.2	157.0	337
Mozambique	2,868	5.0	1.2	0.3	0.3	2
Niger	7,375	1.4	0.1	0.0	0.0	0
Nigeria	25,940	466.1	8.7	4.8	4.5	18

(continued)

Table I.4. Annual Nutrient Consumption in Africa – 1993-1995 (continued)

Country	Area ('000 ha)	NPK ('000 mt)	N	P_2O_5	K_2O	NPK
			(kg/ha)			
Sub-Saharan Africa (continued)						
Reunion	35	16.2	158.1	143.3	160.3	458
Rwanda	675	1.6	1.2	1.0	0.1	2
Senegal	2,148	20.7	4.7	3.4	1.6	10
Sierra Leone	490	2.5	1.8	1.6	1.6	5
Somalia	854	0.0	0.0	0.0	0.0	0
Sudan	10,784	66.2	4.8	1.3	0.0	6
Swaziland	125	12.4	56.0	18.9	24.5	99
Tanzania United Republic	5,362	45.9	6.0	1.7	0.9	9
Togo	1,179	11.1	4.5	2.9	2.0	9
Uganda	3,697	1.8	0.3	0.1	0.1	0
Zaire	6,032	3.5	0.4	0.0	0.2	1
Zambia	1,092	76.3	46.8	15.4	7.7	70
Zimbabwe	2,525	145.2	30.7	16.0	10.8	58
Subtotal	111,137	1,341.1				
Total	132,862	3,650.5				

Note: Dash (-) = no data available.

Table I.5. Annual Nutrient Requirements in Africa – 1993-1995

Country	NPK	N	P_2O_5	K_2O	NPK
	('000 mt)	(kg/ha)			
North Africa					
Algeria	192.7	34.8	18.1	27.8	80.7
Egypt	992.7	165.1	37.4	36.1	258.6
Libyan Arab Jamahiria	44.5	31.7	23.2	26.4	81.3
Morocco	482.0	36.1	17.1	30.8	84.0
Tunisia	137.1	48.8	21.2	32.1	102.1
Subtotal	1,849.0				
South Africa	913.4	56.8	23.9	35.4	116.1
Sub-Saharan Africa					
Angola	66.4	15.4	6.6	13.1	35.1
Benin	85.0	28.1	14.6	20.5	63.2
Botswana	3.8	11.6	5.5	7.4	24.5
Burkina Faso	237.6	30.3	16.4	20.9	67.6
Burundi	90.1	41.9	19.4	49.7	111.0
Côte d'Ivoire	380.9	32.5	13.7	22.7	68.9
Cameroon	179.6	33.4	17.1	27.2	77.7
Cape Verde	1.8	28.3	10.8	15.8	54.9
Central African Republic	34.0	28.7	15.2	19.8	63.7
Chad	110.5	23.9	15.4	16.0	55.3
Congo	16.4	33.7	18.3	30.2	82.2
Equatorial Guinea	3.5	15.7	7.1	10.9	33.7
Eritrea	13.2	21.1	12.1	16.9	50.1
Ethiopia	504.5	37.0	18.9	28.7	84.6
Gabon	11.9	37.7	16.3	35.2	89.2
Gambia	13.2	37.1	14.0	29.5	80.6
Ghana	307.7	40.8	20.1	28.6	89.5
Guinea	62.6	38.5	10.3	27.3	76.1
Guinea-Bissau	15.5	46.7	12.7	42.8	102.2
Kenya	281.5	52.7	22.9	38.2	113.8
Lesotho	13.7	36.9	19.3	46.3	102.5
Liberia	15.8	35.8	17.1	35.4	88.3
Madagascar	194.7	32.6	19.5	32.5	84.6
Malawi	263.8	38.9	37.0	54.1	130.0
Mali	251.1	32.8	18.6	23.5	74.9
Mauritania	18.7	25.2	25.0	18.2	68.4
Mauritius	26.7	121.7	38.2	169.7	329.6
Mozambique	179.2	31.6	14.1	16.9	62.6
Namibia	6.8	26.3	14.3	20.1	60.7
Niger	207.0	11.1	7.3	9.6	28.0

(continued)

Table I.5. Annual Nutrient Requirements in Africa – 1993-1995 (continued)

Country	NPK	N	P_2O_5	K_2O	NPK
	('000 mt)	(kg/ha)			
Sub-Saharan Africa (continued)					
Nigeria	2,725.1	47.7	20.9	36.5	105.1
Reunion	15.5	136.8	137.9	162.6	437.3
Rwanda	83.9	44.7	25.0	54.7	124.4
Senegal	172.9	36.3	22.0	22.2	80.5
Sierra Leone	43.6	39.7	17.8	31.5	89.0
Somalia	56.0	31.7	12.9	20.9	65.5
Sudan	453.5	19.2	9.9	12.9	42.0
Swaziland	22.1	79.0	27.5	69.8	176.3
Tanzania United Republic	499.5	43.3	20.9	28.9	93.1
Togo	66.5	25.7	14.7	16.0	56.4
Uganda	450.4	47.9	27.7	46.2	121.8
Zaire	386.1	28.3	14.7	21.0	64.0
Zambia	94.1	50.5	13.9	21.8	86.2
Zimbabwe	255.0	45.2	13.9	41.9	101.0
Subtotal	8,921.4				
Total	11,683.8				

Table I.6. Assessment of Annual Crop Nutrient Requirements in North Africa – 1993-1995

Group	Crop	N	P_2O_5	K_2O	NPK	(%)
		(mt)				
Beverages	Tobacco	840	333	886	2,059	0.1
Cereals	Barley	67,704	27,417	69,087	164,208	7.6
	Maize	149,344	67,559	79,228	296,131	13.7
	Millet	255	213	233	701	0.0
	Rice	115,163	54,738	93,850	263,751	12.2
	Sorghum	20,132	10,572	12,670	43,374	2.0
	Wheat	313,352	178,223	249,581	741,156	34.4
	Others	1,981	917	1,814	4,712	0.2
	Subtotal	667,931	339,639	506,463	1,514,033	70.1
Fibers	Cotton	39,905	30,361	19,132	89,398	4.1
	Jute	51	30	64	145	0.0
	Others	168	83	130	381	0.0
	Subtotal	40,124	30,474	19,326	98,924	4.1
Fruits	Apples	1,019	553	1,643	3,215	0.1
	Bananas	1,692	718	5,317	7,727	0.4
	Citrus	10,933	4,929	18,177	34,039	1.6
	Grapes	5,827	2,528	7,846	16,201	0.8
	Others	5,668	2,215	8,108	15,991	0.7
	Subtotal	25,139	10,943	41,091	77,173	3.6
Nuts	Almonds	2,482	1,184	1,076	4,742	0.2
	Walnuts	48	22	20	90	0.0
	Others	15	7	7	29	0.0
	Subtotal	2,545	1,213	1,103	4,861	0.2
Oil Seeds	Groundnuts	3,591	1,818	1,382	6,791	0.3
	Soybeans	5,422	1,311	2,296	9,029	0.4
	Others	64,108	19,697	16,728	100,533	4.7
	Subtotal	73,121	22,826	20,406	116,353	5.4

(continued)

Table I.6. Assessment of Annual Crop Nutrient Requirements in North Africa – 1993-1995 (continued)

Group	Crop	N	P_2O_5	K_2O	NPK	(%)
		(mt)				
Pulses	Beans	12,005	6,482	10,921	29,408	1.4
	Peas	4,248	1,810	3,231	9,289	0.4
	Others	700	267	528	1,495	0.1
	Subtotal	16,953	8,559	14,680	40,192	1.9
Roots and Tubers	Potatoes	19,040	15,234	29,839	64,113	3.0
	Taro	557	264	552	1,373	0.1
	Others	595	320	955	1,870	0.1
	Subtotal	20,192	15,818	31,346	67,356	3.2
Sugar	Beet	10,373	4,217	17,972	32,562	1.5
	Cane	21,311	10,500	36,456	68,267	3.2
	Subtotal	31,684	14,717	54,428	100,829	4.7
Vegetables	Cabbages	3,825	1,459	4,310	9,594	0.4
	Cauliflower	1,022	390	1,152	2,564	0.1
	Cucumbers	13,827	8,252	15,924	38,003	1.8
	Tomatoes	26,014	8,615	27,434	62,063	2.9
	Others	13,700	5,223	10,692	29,615	1.4
	Subtotal	58,388	23,939	59,512	141,839	6.6
Total		936,917	468,461	749,241	2,154,619	99.9

Table I.7 Assessment of Annual Crop Nutrient Requirements in sub-Saharan Africa – 1993-1995

Group	Crop	N	P_2O_5	K_2O	NPK	(%)
		(mt)				
Beverages	Coffee	43,108	11,867	28,693	83,668	1.0
	Tea	14,810	5,830	8,059	28,699	0.3
	Tobacco	27,646	10,578	28,330	66,554	0.8
	Subtotal	85,564	28,275	65,082	178,921	2.1
Cereals	Barley	36,744	15,214	39,354	91,312	1.0
	Maize	824,107	360,032	452,120	1,636,259	18.8
	Millet	372,578	308,429	357,914	1,038,921	11.9
	Rice	288,595	133,341	249,864	671,800	7.7
	Sorghum	523,980	265,069	343,856	1,132,905	13.0
	Wheat	92,024	51,205	78,245	221,474	2.5
	Others	1,016	450	968	2,434	0.0
	Subtotal	2,139,044	1,133,740	1,522,321	4,795,105	54.9
Fibers	Cotton	158,872	113,019	76,881	348,772	4.0
	Jute	392	237	483	1,112	0.0
	Others	1,594	544	695	2,833	0.0
	Subtotal	160,858	113,800	78,059	352,717	4.0
Fruits	Apples	19	10	29	58	0.0
	Bananas	21,268	9,228	65,848	96,344	1.1
	Citrus	8,050	3,458	13,297	24,805	0.3
	Grapes	168	75	222	465	0.0
	Pineapples	10,975	2,992	14,870	28,837	0.3
	Plantains	79,891	34,230	128,148	242,269	2.8
	Others	6,126	2,573	9,518	18,217	0.2
	Subtotal	126,497	52,566	231,932	410,995	4.7
Nuts	Almonds	5	2	2	9	0.0
	Others	2,382	1,065	1,063	4,510	0.1
	Subtotal	2,387	1,067	1,065	4,519	0.1

(continued)

Table I.7 Assessment of Annual Crop Nutrient Requirements in sub-Saharan Africa – 1993-1995 (continued)

Group	Crop	N	P_2O_5	K_2O	NPK	(%)
		(mt)				
Oil Seeds	Groundnuts	310,383	153,910	124,119	588,412	6.8
	Soybeans	39,838	9,736	17,217	66,791	0.8
	Others	39,080	12,241	10,295	61,616	0.7
	Subtotal	389,301	175,887	151,631	716,819	8.3
Pulses	Beans	73,890	39,899	66,789	180,578	2.1
	Peas	17,230	8,065	13,559	38,854	0.4
	Others	942	353	731	2,026	0.0
	Subtotal	92,062	48,317	81,079	221,458	2.5
Roots and tubers	Cassava	380,412	176,593	304,244	861,249	9.9
	Potatoes	15,007	11,988	22,920	49,915	0.6
	Taro	18,385	8,940	17,715	45,040	0.5
	Yams	136,191	60,655	157,517	354,363	4.1
	Others	25,230	13,636	40,513	79,379	0.9
	Subtotal	575,225	271,812	542,909	1,389,946	16.0
Sugar	Cane	69,402	33,821	114,468	217,691	2.5
Tree Crops	Cocoa bean	68,861	31,191	36,877	136,929	1.6
	Coconuts	138,189	50,103	36,223	224,515	2.6
	Oil palm	4,051	2,254	5,069	11,374	0.1
	Rubber natural	3,130	1,411	2,693	7,234	0.1
	Subtotal	214,231	84,959	80,862	380,052	4.4
Vegetables	Cabbages	1,174	465	1,269	2,908	0.0
	Cauliflower	35	14	37	86	0.0
	Cucumbers	1,884	1,134	2,169	5,187	0.1
	Tomatoes	6,283	2,054	6,384	14,721	0.2
	Others	7,819	3,004	6,050	16,873	0.2
	Subtotal	17,195	6,671	15,909	39,775	0.5
Total		3,871,766	1,950,915	2,885,317	8,707,998	100.0

Table I.8. Assessment of Annual Crop Nutrient Requirements in South Africa – 1993-1995

Group	Crop	N	P_2O_5	K_2O	NPK	(%)
		(mt)				
Beverages	Hops	5	1	2	8	0.0
	Tea	497	170	269	936	0.1
	Tobacco	1,536	535	1,564	3,635	0.4
	Subtotal	2,038	706	1,835	4,579	0.5
Cereals	Barley	6,918	2,515	6,307	15,740	1.8
	Maize	257,956	103,768	123,969	485,693	54.2
	Millet	280	201	226	707	0.1
	Rice	77	32	55	164	0.0
	Sorghum	12,177	5,777	6,838	24,792	2.8
	Wheat	67,513	34,316	46,616	148,445	16.6
	Others	872	404	745	2,021	0.2
	Subtotal	345,793	147,013	184,756	677,562	75.7
Fibers	Cotton	2,987	2,101	1,329	6,417	0.7
	Jute	28	16	34	78	0.0
	Others	57	19	25	101	0.0
	Subtotal	3,072	2,136	1,388	6,596	0.7
Fruits	Apples	764	373	1,182	2,319	0.3
	Bananas	440	173	1,340	1,953	0.2
	Citrus	3,049	1,172	4,955	9,176	1.0
	Grapes	7,747	3,004	10,017	20,768	2.3
	Pineapples	656	168	909	1,733	0.2
	Others	1,428	602	2,029	4,059	0.5
	Subtotal	14,084	5,492	20,432	40,008	4.5
Oil Seeds	Groundnuts	6,494	2,880	2,256	11,630	1.3
	Soybeans	5,614	1,253	2,226	9,093	1.0
	Others	19,535	5,838	3,451	28,824	3.2
	Subtotal	31,643	9,971	7,933	49,547	5.5
Pulses	Beans	1,993	977	1,686	4,656	0.5
	Peas	137	61	103	301	0.0
	Subtotal	2,130	1,038	1,789	4,957	0.5

(continued)

Table I.8. Assessment of Annual Crop Nutrient Requirements in South Africa – 1993-1995 (continued)

Group	Crop	N	P_2O_5	K_2O	NPK	(%)
		(mt)				
Roots and Tubers	Potatoes	7,919	5,641	11,946	25,506	2.8
	Others	223	119	358	700	0.1
	Subtotal	8,142	5,760	12,304	26,206	2.9
Sugar	Cane	22,422	10,410	38,072	70,904	7.9
Vegetables	Cabbages	1,774	604	1,950	4,328	0.5
	Cauliflower	241	82	265	588	0.1
	Cucumbers	1,372	701	1,597	3,670	0.4
	Tomatoes	1,686	489	1,729	3,904	0.4
	Others	1,447	559	1,158	3,164	0.4
	Subtotal	6,520	2,435	6,699	15,654	1.8
Total		435,844	184,961	275,208	896,013	100.0

Table I.9. Average Crop Production in North Africa

Group	Crop	Crop Production (1964-66)	Crop Production (1979-81)	Crop Production (1993-95)	Annual Rate of Increase (1981-95)
		('000 mt)			(%)
Beverages	Tobacco	11	16	15	-0.4
Cereals	Barley	1,840	2,791	2,772	0.0
	Maize	2,473	3,406	5,479	4.1
	Millet	7	6	9	3.3
	Rice	1,864	2,400	4,577	6.0
	Sorghum	863	670	767	1.0
	Wheat	4,602	5,575	9,818	5.1
	Others	47	125	94	-1.7
Fibers	Cotton	1,422	1,358	869	-2.4
	Jute	5	10	2	-5.3
	Others	9	24	14	-2.8
Fruits	Apples	40	129	792	34.3
	Bananas	66	128	542	21.6
	Citrus	1,675	2,775	3,896	2.7
	Grapes	2,165	1,052	1,273	1.4
	Others	903	1,304	2,189	4.5
Nuts	Almonds	32	83	135	4.2
	Walnuts	6	5	3	-2.7
	Others	0	0	1	-
Oil Seeds	Groundnuts	58	74	73	-0.1
	Soybeans	0	110	66	-2.7
	Others	779	1,224	1,699	2.6
Pulses	Beans	538	416	414	0.0
	Peas	146	129	132	0.2
	Others	68	22	29	2.1
Roots and tubers	Potatoes	891	2,408	3,528	3.1
	Taro	33	96	118	1.5
	Others	87	94	164	5.0
Sugar	Beet	311	2,411	4,128	4.7
	Cane	4,939	9,168	14,379	3.8
Vegetables	Cabbages	253	375	529	2.7
	Cauliflower	62	118	141	1.3
	Cucumbers	2,437	3,712	4,163	0.8
	Tomatoes	1,857	3,607	7,103	6.5
	Others	1,471	2,188	3,560	4.2

Note: Dash (-) = no data available.

Table I.10. Average Crop Production in sub-Saharan Africa

Group	Crop	Crop Production (1964-66)	(1979-81)	(1993-95)	Annual Rate of Increase (1981-95)
		----------('000 mt)		----------	(%)
Beverages	Coffee	1,146	1,187	1,055	-0.7
	Tea	74	194	336	4.9
	Tobacco	209	234	418	5.2
Cereals	Barley	773	1,115	1,337	1.3
	Maize	9,946	13,810	25,805	5.8
	Millet	6,697	7,675	11,715	3.5
	Rice	3,800	6,121	9,681	3.9
	Sorghum	9,238	11,198	16,281	3.0
	Wheat	980	1,419	2,432	4.8
	Others	14	48	45	-0.4
Fibers	Cotton	1,489	1,679	2,799	4.4
	Jute	14	10	13	2.0
	Others	421	156	84	-3.1
Fruits	Apples	13	9	12	2.2
	Bananas	3,570	4,799	6,009	1.7
	Citrus	1,758	2,941	3,576	1.4
	Grapes	2	26	33	1.8
	Pineapples	833	1,461	1,777	1.4
	Plantains	10,023	15,343	21,617	2.7
	Others	1,364	2,119	2,699	1.8
Nuts	Others	250	175	170	-0.2
Oil Seeds	Groundnuts	5,248	4,114	5,465	2.2
	Soybeans	73	185	426	8.7
	Others	519	685	876	1.9
Pulses	Beans	1,260	1,915	2,169	0.9
	Peas	390	473	470	0.0
	Others	41	45	38	-1.0
Roots and tubers	Cassava	34,675	48,971	82,669	4.6
	Potatoes	995	1,999	2,420	1.4
	Taro	2,936	3,307	3,287	0.0
	Yams	10,162	10,475	31,431	13.3
	Others	3,098	5,241	6,843	2.0
Sugar	Cane	18,588	35,286	40,101	0.9

(continued)

Table I.10. Average Crop Production in sub-Saharan Africa (continued)

Group	Crop	Crop Production (1964-66)	(1979-81)	(1993-95)	Annual Rate of Increase (1981-95)
		('000 mt)			(%)
Tree crops	Cocoa bean	1,001	1,037	1,373	2.2
	Coconuts	1,263	1,601	1,704	0.4
	Oil palm	809	683	749	0.6
	Rubber natural	169	202	299	3.2
Vegetables	Cabbages	46	94	143	3.5
	Cauliflower	2	1	4	20.0
	Cucumbers	286	420	500	1.3
	Tomatoes	576	912	1,451	3.9
	Others	863	1,335	2,004	3.3

Table I.11. Average Crop Production in South Africa

Group	Crop	Crop Production (1964-66)	(1979-81)	(1993-95)	Annual Rate of Increase (1981-95)
		('000 mt)			(%)
Beverages	Tea	2	8	11	2.5
	Tobacco	27	37	24	-2.3
Cereals	Barley	36	102	268	10.8
	Maize	4,693	11,322	9,312	-1.2
	Millet	11	15	10	-2.2
	Rice	2	3	3	0.0
	Sorghum	328	540	442	-1.2
	Wheat	764	1,966	1,983	0.1
	Others	122	84	43	-3.3
Fibers	Cotton	45	151	62	-3.9
	Jute	2	1	1	0.0
	Others	2	6	3	-3.3
Fruits	Apples	160	394	548	2.6
	Bananas	32	111	134	1.4
	Citrus	539	733	999	2.4
	Grapes	732	1,202	1,553	1.9
	Pineapples	109	217	119	-3.0
	Others	281	431	533	1.6
Oil Seeds	Groundnuts	207	297	127	-3.8
	Soybeans	3	32	65	6.9
	Others	100	393	400	0.1
Pulses	Beans	45	84	65	-1.5
	Peas	7	8	4	-3.3
Roots and tubers	Potatoes	399	747	1,345	5.3
	Others	37	46	62	2.3
Sugar	Cane	11,057	17,345	14,570	-1.1
Vegetables	Cabbages	93	217	228	0.3
	Cauliflower	29	46	31	-2.2
	Cucumbers	123	268	397	3.2
	Tomatoes	207	323	426	2.1
	Others	194	313	393	1.7

Table I.12. Average Crop Yield in North Africa

Group	Crop	Crop Production (1964-66)	(1979-81)	(1993-95)	Annual Rate of Increase (1981-95)
		(kg/ha)			(%)
Beverages	Tobacco	1,034	1,077	1,040	-0.2
Cereals	Barley	896	1,022	933	-0.6
	Maize	1,589	1,591	2,414	3.4
	Millet	508	1,006	1,021	0.1
	Rice	4,257	4,823	5,208	0.5
	Sorghum	1,355	1,531	1,893	1.6
	Wheat	1,025	1,237	1,885	3.5
	Others	498	667	885	2.2
Fibers	Cotton	1,282	2,135	1,971	-0.5
	Jute	2,665	2,309	2,000	-0.9
	Others	386	687	836	1.4
Fruits	Grapes	5,357	5,003	5,745	1.0
Oil Seeds	Groundnuts	1,656	1,737	1,641	-0.4
	Soybeans	-	1,833	2,039	0.7
	Others	884	1,598	1,760	0.7
Pulses	Beans	900	1,030	1,004	-0.2
	Peas	803	940	1,101	1.1
	Others	662	545	703	1.9
Roots and tubers	Potatoes	9,347	11,548	13,542	1.2
	Taro	33,000	32,000	29,583	-0.5
	Others	21,418	23,000	25,278	0.7
Sugar	Beet	14,842	29,008	46,774	4.1
	Cane	89,270	84,610	86,616	0.2
Vegetables	Cabbages	24,169	14,913	18,127	1.4
	Cauliflower	21,974	15,333	15,315	0.0
	Cucumbers	14,555	12,908	16,497	1.9
	Tomatoes	14,245	20,160	25,271	1.7
	Others	9,241	9,400	11,601	1.6

Note: Dash (-) = no data available.

Table I.13. Average Crop Yield in sub-Saharan Africa

Group	Crop	Crop Production (1964-66)	(1979-81)	(1993-95)	Annual Rate of Increase (1981-95)
		(kg/ha)			(%)
Beverages	Coffee	476	538	530	-0.1
	Tea	809	1,194	1,370	1.0
	Tobacco	611	750	877	1.1
Cereals	Barley	803	1,456	1,180	-1.3
	Maize	924	1,115	1,294	1.1
	Millet	691	687	684	0.0
	Rice	1,316	1,479	1,877	1.8
	Sorghum	736	782	771	-0.1
	Wheat	1,137	1,584	1,541	-0.2
	Others	568	1,117	1,282	1.0
Fibers	Cotton	799	891	996	0.8
	Jute	825	634	697	0.7
	Others	695	747	765	0.2
Fruits	Grapes	-	4,388	5,122	1.1
Oil Seeds	Groundnuts	727	800	791	-0.1
	Soybeans	688	998	1,068	0.5
	Others	386	461	497	0.5
Pulses	Beans	679	728	685	-0.4
	Peas	566	634	618	-0.2
	Others	464	870	794	-0.6
Roots and tubers	Cassava	5,897	6,600	6,601	0.0
	Potatoes	7,304	7,942	8,216	0.2
	Taro	4,585	4,361	4,680	0.5
	Yams	6,630	6,628	7,006	0.4
	Others	5,970	6,060	5,791	-0.3
Sugar	Cane	47,688	57,391	57,065	0.0
Tree crops	Cocoa bean	313	361	451	1.7
Vegetables	Cabbages	9,112	13,584	16,973	1.7
	Cucumbers	14,353	13,790	14,364	0.3
	Tomatoes	7,539	8,254	8,975	0.6
	Others	6,931	7,914	7,438	-0.4

Note: Dash (-) = no data available.

Table I.14. Average Crop Yield in South Africa

Group	Crop	Crop Production (1964-66)	(1979-81)	(1993-95)	Annual Rate of Increase (1981-95)
		(kg/ha)			(%)
Beverages	Hops	1,000	682	739	0.6
	Tea	2,000	1,534	1,062	-2.1
	Tobacco	860	1,018	1,352	2.2
Cereals	Barley	964	1,258	2,230	5.2
	Maize	1,086	2,634	2,224	-1.0
	Millet	567	682	455	-2.2
	Rice	2,000	3,000	3,000	0.0
	Sorghum	755	2,515	2,034	-1.3
	Wheat	637	1,111	1,700	3.5
	Others	429	268	59	-5.2
Fibers	Cotton	700	1,355	916	-2.2
	Jute	835	1,000	1,000	0.0
	Others	667	1,064	750	-2.0
Fruits	Grapes	8,963	10,671	10,131	-0.3
Oil Seeds	Groundnuts	653	1,211	997	-1.2
	Soybeans	429	1,263	1,175	-0.5
	Others	584	848	729	-0.9
Pulses	Beans	570	1,294	1,174	-0.6
	Peas	845	959	1,090	0.9
Roots and tubers	Potatoes	8,809	14,094	24,154	4.8
	Others	2,445	3,538	4,452	1.7
Sugar	Cane	72,266	75,523	46,253	-2.6
Vegetables	Cabbages	31,000	43,334	35,967	-1.1
	Cauliflower	28,670	22,935	31,000	2.4
	Cucumbers	10,789	13,961	13,551	-0.2
	Tomatoes	29,619	26,944	29,728	0.7
	Others	21,919	16,559	11,566	-2.0

Appendix II

Table II.1. Agricultural Land Area in Mali by Soil Type

USDA Classification	FAO Classification	Area ('000 ha)	Area (%)
Alfisols	Luvisols	15,928.8	12.74
	Planosols	22.3	0.02
	Podzoluvisols/sands	19,445.7	15.55
	Subtotal	35,396.8	28.31
Aridisols	Yermosols	32,235.0	25.78
Entisols	Regosols	12,514.0	10.01
Inceptisols	Eutrict Cambisols	242.7	0.19
	Fluvisols	171.9	0.14
	Gleysols	5,370.1	4.30
	Vertic Cambisols	417.7	0.33
	Subtotal	6,202.4	4.96
Lithic/subg	Lithosols	15,103.4	12.08
Mollisols	Solonchaks	19.7	0.02
Psamments	Arenosols	18,746.6	14.99
Rocks	Rock/debris	492.2	0.39
Salt flats	Salt flats	264.4	0.21
Ultisols	Ferric Acrisols	559.9	0.45
	Nitosols	2,099.8	1.68
	Plinthic Acrisols	168.1	0.13
	Subtotal	2,827.8	2.26
Vertisols	Vertisols	1,075.7	0.86
Water	Water	139.4	0.11
Total		125,017.4	99.98

Note: FAO: FAO soil classification system.
USDA: US soil classification system.

Table II.2. Agricultural Land Area in Zimbabwe by Soil Type

USDA Classification	FAO Classification	Area ('000 ha)	Area (%)
Alfisols	Calcic Luvisols	2,118.0	5.43
	Chromic Luvisols	5,454.4	13.98
	Ferric Luvisols	14,279.0	36.59
	Gleyic Luvisols	1,224.5	3.14
	Lithosols-Luvisols	38.1	0.10
	Orthic Luvisols	124.7	0.32
	Subtotal	23,238.7	59.56
Fluvents	Eutric Fluvisols	5.8	0.01
Inceptisols	Chromic Cambisols	66.8	0.17
	Lithosols Cambisols	4,842.8	12.41
	Vertic Cambisols	634.1	1.63
	Subtotal	5,543.7	14.21
Oxisols	Orthic Ferralsols	0.0	0.00
	Rhodic Ferralsols	886.0	2.27
	Subtotal	886.0	2.27
Psamments	Cambic Arenosols	4,944.6	12.67
	Ferralitic Arenosols	65.5	0.17
	Luvic Arenosols	1,691.3	4.33
	Subtotal	6,701.4	17.17
Ultisols	Eutric Nitosols	1,372.6	3.52
Vertisols	Vertisols	886.2	2.27
Water	Water	384.6	0.99
Total		39,019.0	100.00

Note: FAO: FAO soil classification system.
USDA: US soil classification system.

Table II.3. Average Crop Production in Mali

Group	Crop	Crop Production (1964-66)	(1979-81)	(1993-95)	Annual Rate of Increase (1981-95)
		('000 mt)			(%)
Beverages	Tobacco	1	0	1	-
Cereals	Maize	99	61	309	27.1
	Millet	411	461	808	5.0
	Rice	159	169	455	11.3
	Sorghum	304	341	729	7.6
	Wheat	2	2	3	3.3
Fibers	Cotton	28	129	316	9.7
	Jute	0	2	1	-3.3
Fruits	Others	8	12	15	1.7
Oil seeds	Groundnuts	137	136	187	2.5
Roots and tubers	Cassava	30	59	2	-6.4
	Yams	8	15	13	-0.9
	Others	32	49	11	-5.2
Sugar	Cane	25	184	269	3.1
Vegetables	Tomatoes	6	7	9	1.9
	Others	3	4	8	6.7

Note: Dash (-) = no data available.

Table II.4. Average Crop Yield in Mali

Group	Crop	Crop Production (1964-66)	(1979-81)	(1993-95)	Annual Rate of Increase (1981-95)
		- - - - - - - - - - - -	(kg/ha)	- - - - - - - - - - -	(%)
Beverages	Tobacco	1,000	330	670	6.9
Cereals	Maize	866	1,167	1,124	-0.2
	Millet	731	716	593	-1.1
	Rice	945	1,026	1,654	4.1
	Sorghum	800	785	739	-0.4
	Wheat	1,000	1,000	1,994	6.6
Fibers	Cotton	639	1,179	1,465	1.6
	Jute	-	667	571	-1.0
Oil seeds	Groundnuts	986	823	837	0.1
Roots and tubers	Yams	4,165	3,668	3,079	-1.1
	Others	10,557	12,250	5,500	-3.7
Sugar	Cane	25,000	50,226	80,880	4.1
Vegetables	Tomatoes	6,000	3,335	4,500	2.3

Note: Dash (-) = no data available.

Table II.5. Average Crop Production in Zimbabwe

Group	Crop	Crop Production (1964-66)	(1979-81)	(1993-95)	Annual Rate of Increase (1981-95)
		('000 mt)			(%)
Beverages	Coffee	0	5	6	1.3
	Tea	2	10	14	2.7
	Tobacco	125	104	195	5.8
Cereals	Barley	1	27	13	-3.5
	Maize	813	1,829	1,726	-0.4
	Millet	234	153	65	-3.8
	Rice	3	0	1	-
	Sorghum	69	85	80	-0.4
	Wheat	6	179	199	0.7
	Others	0	1	1	0.0
Fibers	Cotton	17	158	153	-0.2
Fruits	Apples	2	4	6	3.3
	Bananas	31	54	82	3.5
	Citrus	27	46	92	6.7
	Grapes	0	2	2	0.0
	Others	0	1	1	0.0
Oil seeds	Groundnuts	91	102	62	-2.6
	Soybeans	0	86	96	0.8
	Others	2	12	40	15.6
Pulses	Beans	18	22	44	6.7
Roots and tubers	Cassava	43	55	130	9.1
	Potatoes	21	21	30	2.9
	Others	0	1	2	6.7
Sugar	Cane	1,575	2,878	2,634	-0.6
Vegetables	Tomatoes	8	10	12	1.3
	Others	2	3	6	6.7

Note: Dash (-) = no data available.

Table II.6. Average Crop Yield in Zimbabwe

Group	Crop	Crop Production (1964-66)	(1979-81)	(1993-95)	Annual Rate of Increase (1981-95)
		-----------	(kg/ha)	-----------	(%)
Beverages	Coffee	-	1,155	1,134	-0.1
	Tea	717	2,500	2,800	0.8
	Tobacco	1,569	1,896	2,349	1.6
Cereals	Barley	-	5,004	2,112	-3.9
	Maize	1,064	1,667	1,279	-1.6
	Millet	596	432	239	-3.0
	Sorghum	739	611	530	-0.9
	Wheat	2,433	4,795	4,901	0.1
Fibers	Cotton	1,342	1,601	935	-2.8
Oil seeds	Groundnuts	536	555	449	-1.3
	Soybeans	-	1,962	1,649	-1.1
	Others	538	584	318	-3.0
Pulses	Beans	524	570	665	1.1
Roots and tubers	Cassava	3,024	2,983	3,939	2.1
	Potatoes	10,665	15,541	15,165	-0.2
	Others			2,000	-
Sugar	Cane	98,417	102,786	105,347	0.2
Vegetables	Tomatoes	7,670	10,000	6,165	-2.6

Note: Dash (-) = no data available.

Appendix III

Table III.1. Nutrient Balance and Requirements for Crop Production Alternatives – Sensitivity Analysis for Mali

Nutrient Depletion	NPK	N	P_2O_5	K_2O	NPK
	('000 mt)	(kg/ha)			
A1	-204.3	-29.4	-7.3	-24.2	-60.9
A2	-170.4	-26.3	-5.2	-19.1	-50.6
A3	-128.5	-21.9	-2.8	-13.4	-38.1
A4	-93.2	-18.5	-0.7	-8.4	-27.6
A5	-139.2	-21.8	-3.4	-16.4	-41.6
A6	-120.4	-19.4	-1.6	-15.0	-36.0
A7	-94.6	-17.1	-0.2	-11.0	-28.3
A8	-124.1	-14.4	-3.0	-19.7	-37.1
A9	-99.9	-9.1	-1.7	-17.3	-28.1
A10	-81.7	-7.7	-0.1	-12.2	-20.0
A11	-66.3	-8.0	-1.5	-8.9	-15.4

Nutrient Requirements	NPK	N	P_2O_5	K_2O	NPK
	('000 mt)	(kg/ha)			
A1	251.1	32.8	18.6	23.5	74.9
A2	217.5	29.8	16.7	18.4	64.9
A3	175.2	25.3	14.3	12.7	52.3
A4	140.3	21.9	12.2	7.7	41.8
A5	186.2	25.2	14.6	15.7	55.2
A6	167.4	22.9	12.8	14.3	50.0
A7	141.5	20.5	11.3	10.3	42.1
A8	227.3	29.8	16.6	21.4	67.8
A9	211.5	27.6	15.9	19.6	63.1
A10	187.9	26.2	14.3	15.5	56.0
A11	159.0	23.5	12.7	11.2	47.4

A1	Using 30% of crop residue.
A2	Using 50% of crop residue.
A3	Using 70% of crop residue.
A4	Using 90% of crop residue.
A5	Using 50% of crop residue and reducing leaching and erosion losses by 20%.
A6	Using 50% of crop residue and reducing leaching and erosion losses by 40%.
A7	Using 70% of crop residue and reducing leaching and erosion losses by 40%.
A8	Using 30% of crop residue, N fixation, and reducing losses by 20%.
A9	Using 30% of crop residue, N fixation, and reducing losses by 40%.
A10	Using 50% of crop residue and N fixation.
A11	Using 70% of crop residue and N fixation.

Table III.2. Nutrient Balance and Requirements for Crop Production Alternatives – Sensitivity Analysis for Zimbabwe

Nutrient Depletion	NPK	N	P_2O_5	K_2O	NPK
	('000 mt)	(kg/ha)			
A1	-118.7	-19.8	-1.7	-25.5	-47.0
A2	-92.7	-16.4	-0.7	-19.6	-36.7
A3	-57.4	-11.0	0.7	-12.4	-22.7
A4	-29.6	-7.1	1.8	-6.4	-11.7
A5	-62.9	-10.6	0.9	-15.2	-24.9
A6	-46.5	-7.7	2.2	-12.9	-18.4
A7	-25.0	5.7	3.0	-8.0	-10.7
A8	-44.8	1.9	2.8	-19.4	-18.5
A9	-15.0	2.8	4.2	-13.7	-6.7
A10	8.3	7.3	5.1	-9.9	2.5
A11	13.4	10.4	5.9	4.8	11.5

Nutrient Requirements	NPK	N	P_2O_5	K_2O	NPK
	('000 mt)	(kg/ha)			
A1	255.0	45.2	13.9	41.9	101.0
A2	228.8	41.8	12.9	36.0	90.0
A3	193.8	36.5	11.5	28.8	76.8
A4	165.7	32.5	10.3	22.8	65.6
A5	199.4	36.1	11.3	31.6	79.0
A6	182.7	33.1	10.0	29.3	72.4
A7	161.7	30.3	9.2	24.4	63.9
A8	234.1	41.5	12.4	38.8	92.7
A9	216.8	38.8	12.0	35.1	85.9
A10	201.3	37.3	11.1	31.3	79.7
A11	178.4	34.2	10.3	26.2	70.7

A1	Using 30% of crop residue.
A2	Using 50% of crop residue.
A3	Using 70% of crop residue.
A4	Using 90% of crop residue.
A5	Using 50% of crop residue and reducing leaching and erosion losses by 20%.
A6	Using 50% of crop residue and reducing leaching and erosion losses by 40%.
A7	Using 70% of crop residue and reducing leaching and erosion losses by 40%.
A8	Using 30% of crop residue, N fixation, and reducing losses by 20%.
A9	Using 30% of crop residue, N fixation, and reducing losses by 40%.
A10	Using 50% of crop residue and N fixation.
A11	Using 70% of crop residue and N fixation.

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